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# RICE BRAN STABILIZATION AND RECOVERY OF EDIBLE OIL - TECHNICAL AND FINANCIAL FEASIBILITY

DAVID A. FELLERS
OICD, USDA

JANUARY 19, 1989

United States Department of Agriculture

Office of International Cooperation and Development

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# RICE BRAN STABILIZATION AND RECOVERY OF EDIBLE OIL - TECHNICAL AND FINANCIAL FEASIBILITY

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Rice bran is an oil bearing commodity containing up to 22 percent crude oil. However, it is also a very unstable material and its oil can increase in free fatty acids (FFA)'s from the 2 to 3 percent typical in freshly milled rice bran to as much as 10 percent within a single day. If rice bran is to be utilized for recovery of edible oil, processing must begin immediately after milling to minimize oil loss and to achieve the best economic result. There are two basic approaches to deal with the stability problem: 1) extract the oil as soon as possible after milling, or 2) stabilize the rice bran as soon as possible after milling. Commercial practice in the world today depends almost exclusively on the former but there are recent advances in extruder cooker stabilization technology whose successful practice in the United States, on a limited basis, suggests broader application and extension to developing countries (LDC's).

The purpose of this paper is to consider and evaluate extruder cooker stabilization of rice bran in the overall process of producing edible rice bran oil. Figure 1 presents alternative pathways for the production of edible oil from rice bran where stabilization is included as part of the overall process. Aspects of the various steps outlined in Figure 1 are addressed in an attempt to develop a framework that allow determination of technical and financial feasibility. Figure 1 does not include certain modern oil extraction and refining processes, e.g. miscella or physical refining, that have been demonstrated to give higher yields of edible oil and that are practiced in some countries. This paper is primarily concerned with conditions in LDC's and thus solvent extraction and oil refining processes broadly practiced in LDC's are the chosen processes used here to explore technical and financial feasibility.

It should be pointed out that rice bran quality can vary tremendously, thus Figure 1 includes an alternative pathway that includes a process to improve rice bran quality. However, bran quality may be so poor that only impovements in rice paddy drying, paddy cleaning and grading, and the rice milling process itself will alleviate the problem. Figure 1 also notes an alternative pathway referred to as "rice bran collection". This becomes an issue because there are often many small rice mills (1 MT paddy/hour) in LDCs and it may not be practical to have a stabilizer at every mill. If bran from such mills is to be utilized, it must be collected and stabilized at a central, but local, stabilizer on an expeditious schedule. Rice bran collection is discussed in greater detail later in the paper.

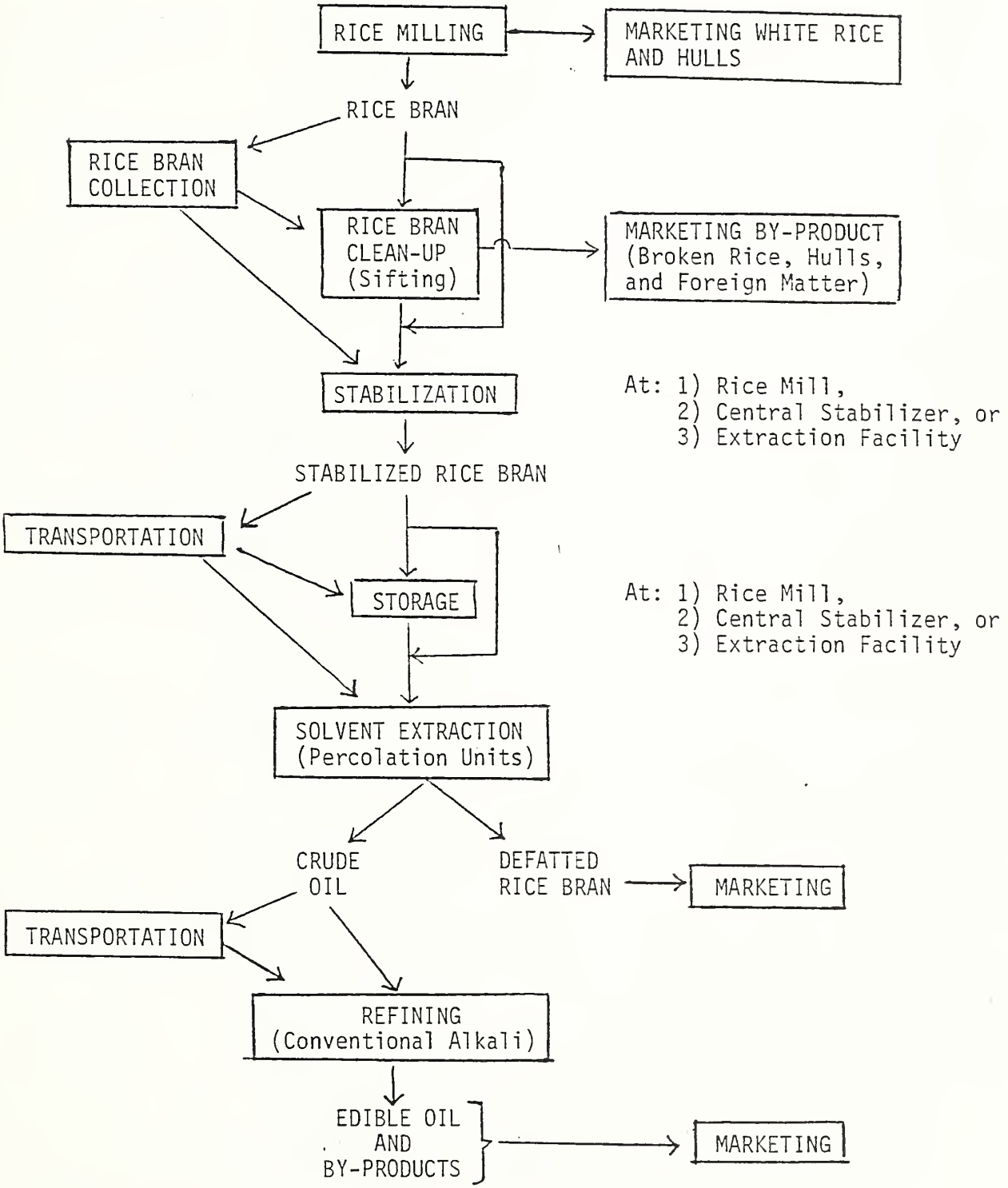
Utilization of rice bran for oil production is expanding rapidly in several Asian countries. An international market has been established for defatted rice bran with prices listed, e.g., in "Oil World" published in West Germany. However, the rice bran stability problem, compounded by poor transportation infrastructure and the small and dispersed nature of many rice mills in LDC's, continues to suppress production of edible rice bran oil. Stabilization at or near the source of rice bran production could effectively alleviate this problem. Agribusinessmen in LDC's may wish to investigate this area for new venture opportunities in their own countries or regions.

## Historical

The birth of the rice bran oil industry occurred in Korea in the 1930's prior to World War II (1). Large quantities of rice were being centrally milled on modern equipment for export to Japan and the large resulting supply of good quality rice bran presented an opportunity for oil recovery. The industry,

FIGURE 1

Schematic Presentation of Alternate Pathways in the Production of Refined, Edible Rice Bran Oil Wherein Rice Bran Stabilization is Part of the Overall Process.



based on hydraulic pressing, spread rapidly to Japan, Taiwan, and Thailand. In the post war period, batch, battery, and eventually continuous solvent extractors were introduced.

In Burma, Thailand, and Taiwan, the export of large quantities of milled rice stimulated rice bran oil production by creating large central supplies of good quality rice bran. In part, the vitality of the rice bran oil industry in these countries has been tied to the milled rice export business and the waxing and waning supply of centrally processed, good quality, inexpensive rice bran.

Food and soap scarcity after the war also stimulated rice bran oil production, especially in Japan (2). Today, increasing consumer income in many developing countries is raising food oil demand. This demand is difficult to meet due to insufficient supplies of domestic oilseeds and, in some cases, the scarcity of foreign exchange for oil imports. Where these conditions exist, e.g. India, Egypt, Korea, and Taiwan, there is a renewed interest in rice bran oil.

## Potential for Rice Bran Oil Production

World production of rice paddy in 1985 was 466 million metric tons (MT) (3) with 94% produced in developing countries. Modern, two-stage milling of rice paddy yields 20 to 24% hulls, 5 to 10% rice bran, and 68 to 74% milled rice. Taking 6% yield of rice bran based on paddy as average, the world rice bran production potential is over 28 million MT. This quantity of bran could yield over 4 million MT of crude rice bran oil or 2 to 3 million MT of refined, edible rice bran oil. The actual quantity of crude oil produced is on the order of 600,000 MT or about 15% of the potential (see Table I.) Approximately 35% of this crude oil is refined for food uses such as cooking and salad oils. In India, refined rice bran oil is hydrogenated for use in vanaspati. Most of the crude oil that is not refined for food use has a high free fatty acid (FFA) content (greater than 10%) and is used industrially, especially in the manufacture of soap.

Table I

Production of Crude Rice Bran Oil

| | 1985 Paddy Production (3) Million MT | Rice Bran as Percent of Paddy | 1985 Potential[a] Crude Oil MT | Actual Crude Oil MT/Year | Year | Reference for Actual Crude Oil Values |
|---|---|---|---|---|---|---|
| India | 91.5 | 5.0 | 686,250 | 320,000 | 1987-88 | (4) |
| Japan | 14.6 | 7.0 | 153,300 | 81,000 | 1987 | (5) |
| PRC (China) | 171.5 | 6.0 | 1,543,500 | 90,000 | 1986 | (6) |
| Korea (South) | 7.8 | 7.0 | 81,900 | 16,650 | 1981 | (7) |
| Thailand | 19.5 | 7.0 | 204,700 | 19,600 | 1984 | (8) |
| Egypt | 2.3 | 7.0 | 24,100 | 8,250 | 1978 | (8) |
| Burma | 15.4 | 5.0 | 115,500 | 8,400 | 1984 | (8) |
| Taiwan | 3.1 | 7.0 | 32,500 | 5,400 | 1985 | (9) |
| Pakistan | 4.5 | 5.0 | 33,800 | 2,600 | 1984 | (8) |
| Indonesia | 38.7 | 5.0 | 290,200 | 12,750 | 1984 | (8) |
| Philippines | 8.3 | 7.0 | 87,100 | 30 | 1984 | (10) |
| World | 466.0 | 6.0 | 4,194,000 | - | - | - |

a. Based on 15% extractables.

Factors Affecting Rice Bran Oil Production

While there is a large potential for rice bran oil, various factors constrain its realization. These are listed in Table II. On the other hand, there are trends and developments leading to increased interest in and production of rice bran oil:

a. Increasing per capita income in many countries has led to increased demand for fats and oils. As the per capita GNP in Korea advanced from $US 243 in 1970 to $US 1,636 in 1981, per capita edible fats and oils consumption increased from 3.6 grams per day to 16.4 grams per day (7). However, the production of oilseeds has not kept pace in Korea and the importation of soybeans for production of edible oil has surged. This has heightened the interest in domestic rice bran and some progress has been made in increasing rice bran oil production.

b. In India, demand for fats and oils exceeds domestic supply by over 1 million metric tons (MT) annually. The Government of India, in an effort to mobilize domestic resources, has developed standards for rice milling, rice bran, and rice bran oil products and is providing incentives to encourage increased production of rice bran oil. Some 30,000 MT of crude oil of low FFA content was conventionally refined (alkali process) in 1986 and used primarily in blends with other oils in the manufacture of vanaspati (11).

Table II

Constraints to Greater Production of Edible Rice Bran Oil

1. Perishable nature of rice bran. Hydrolysis of oil to free fatty acids (FFA's) and glycerol proceeds rapidly after milling and the economic loss is very significant when the objective is to produce a refined, edible oil. Extraction or stabilization of the rice bran immediately after milling is required to avoid this penalty. Delays of more than one or two days before extraction or stabilization render edible oil production uneconomic.

2. The geographically dispersed nature and small size (1 MT paddy/hour; 50 to 100 KG bran/hour) of many rice mills make rice bran expensive to collect. Rapid, low cost, on-site methods of grading rice bran quality (percent crude oil, FFA's, and hull content) at time of purchase are not available and prices paid relative to quality are not established. Also, irregular mill operational schedules make the timing of the rice bran supply uncertain.

3. Continued use of huller mills or single-stage mills that do not separate hulls and bran. Such a mix of hulls and bran has only 5 to 10% oil content which is too low to extract economically.

4. Floury nature of rice bran that prevents its use in percolation-type solvent extractors unless it is first agglomerated or pelleted.

5. Poor quality rice paddy such as that containing high levels of brokens, immature kernels, chalky kernels, mold damaged kernels, and foreign materials. This results in rice bran with higher levels of starch, hulls, and foreign matter that dilutes the oil content to less than 15% making oil extraction less economic. Proper harvesting and drying (slow drying through the critical 18 to 14% moisture range) are important to minimize breakage.

Good paddy cleaning is essential. Paddy graders to remove immature kernels are helpful.

6. Lack of solvent extraction facilities nearby rice mills and thus high transportation and handling costs for rice bran. Rice bran is commonly handled in sacks.

7. Competing markets for rice bran, e.g. hog feeding, and, hesitancy on the part of a rice miller to commit his total bran supply to a single buyer.

8. High levels of waxes, gums, and free fatty acids (FFA's) in crude rice bran oil that make it more difficult and expensive to refine. Takeshita (2) has called it the most difficult oil to refine.

9. Availability of low-cost competing oils such as soybean and palm.

10. Lack of established markets (consumer's knowledge) for rice bran oil, defatted rice bran, and other by-products.

11. In refining plants setup to process other oils but being diverted to process rice bran oil, investment in equipment and process modifications are likely to be required if valuable by-products such as oryzanol, tocopherol, phospholipids, acid oil, and wax are to be recovered and the maximum yield of edible salad oil achieved.

c. Dry extrusion stabilization of rice bran has been recently described (12, 13, 14. 15). This process not only stabilizes but also agglomerates the rice bran making it a suitable feedstock for percolation-type solvent extractors. The process is low-cost and adaptable to various sized rice mills though mills on the order of 1 MT paddy/hour capacity may be too small to be feasible. Stabilization at the rice mill allows stabilized rice bran to be accumulated at the rice mill and then collected periodically on a more cost effective basis. Three large California rice mills are stabilizing rice bran by dry extrusion and exporting stabilized rice bran to Pacific Rim countries for edible oil production.

d. There is also the potential of placing extruders at central locations nearby several small rice mills. This option requires close coordination between mills and stabilizer to insure rapid collection and processing of the rice bran. This option will suffer additional collection costs (more frequent trips with only small quantities of rice bran collected) and a significant penalty in increased FFA's. The development of FFA's tends to be most rapid immediately after milling and can approach 1% FFA or higher per hour (16). Several hours delay before stabilization can result in an increase in FFA's of 5% or more. In conventional alkali refining, this 5% FFA increase is magnified 2 to 3 times resulting in a loss of 10 to 15% edible oil. As can be seen, the most effective use of extrusion stabilization is at the rice mill.

e. Demand for compound (blended) animal feeds is growing in many countries, eapecially in developing countries. The rice bran oil industry in India is growing rapidly and produces defatted rice bran as a by-product. Defatted rice bran has found a market in compound feeds and, furthermore, India has developed a significant export market for defatted rice bran in Europe and Asia (4, 17).

Indian exports have grown from 130,000 MT in 1970-71 to 497,000 in 1982-83 while declining to 346,000 M in 1987-88. Japan, which processes a large portion of its rice bran (Table 1) for oil production, has established domestic feed markets for defatted rice bran sometimes at premium prices over raw rice bran.

f. The rice milling industry continues to modernize. Huller or single-stage mills are being replaced by more efficient two-stage mills. In some countries, larger mills are being built which means a more centralized supply of bran. These are trends that improve the economics of rice bran oil production.

g. The Indian Council of Medical Research recommends consumption of a minimum of 35 grams of fat per day per capita as part of a balanced diet. The per capita consumption of fat in many developing countries does not meet this level. Rice bran oil could contribute to filling this gap and providing essential fatty acids. Linoleic acid is the primary essential fatty acid and rice bran oil contains 36%. The requirement for essential fatty acids is 1 to 2% of calories (18) or approximately 10 to 20 grams per day. Edible rice bran oil has been shown to have a hypocholesterolemic (cholesterol lowering) effect (19) and is a desirable oil for those concerned with coronary heart disease.

h. Newer methods of refining have been developed and adapted, especially in Japan, for use on crude rice bran oil that result in increased yields of edible oil compared to conventional alkali refining. These methods include: 1) miscella solvent (hexane) refining, 2) miscella binary solvent (hexane and alcohol) refining, and 3) physical refining (vacuum-steam distillation of FFA). The miscella refining plants are more expensive to build due to requirements for explosion-proof equipment. Takeshita (2) notes the miscella refining process has special merit for handling crude oils with high FFA levels. Goenka (20) indicates crude rice bran oil with FFA content as high as 30% can be processed by the miscella

binary solvent method. Singhal (21) reported that the installed cost for physical refining is 22% less than a conventional alkali plant and achieves greater yield of edible oil with significantly reduced operational costs and less waste effluent. If new refining plants are to be built, certainly one would want to consider physical refining.

In Japan, Takeshita (2) notes crude rice bran oil with as high as 20% FFA content is sometimes encountered and refined but on average FFA content runs about 10%. He further notes, however, that rice bran that has deteriorated to higher levels of FFA yields oil of darker color and higher levels of unsaponifiable matter. As a practical matter, it would appear that 10 to 15% FFA content is an upper limit for routine production of good quality edible rice bran oil and perhaps less than 7% FFA content where conventional alkali refining predominates and plants are not fully modernized. The Bureau of Indian Standards has a standard for edible crude rice bran oil that stipulates a FFA content of less than 7%; over 7% is considered industrial grade oil. Accordingly, edible rice bran oil production still depends on extraction or stabilization of the rice bran as soon as possible after milling.

## Rice Bran - The Raw Material

Rice bran is the raw material from which crude rice bran oil is obtained. The oil content of commercial bran can vary from 5% in bran produced on huller mills (hulls and bran removed together and comingled) to more than 20% in bran produced on modern two-stage mills where hulls and bran are produced separately. Factors affecting rice bran composition have been discussed extensively (8, 15, 17, 22). Rice bran at 8% yield (based on paddy) from 39 varieties had crude fat contents from 16.2 to 24.2% at 14% moisture (8). It would appear that 20% oil content rice bran is generally achievable on modern

milling equipment with high quality paddy. However, conditions of paddy quality and rice milling are not always ideal and 15% oil content is often quoted as a "typical" level for rice bran.

Table III provides estimates of the effect of paddy quality and milling factors on oil content of rice bran. The magnitude of these effects readily explains why 15% oil content bran is often observed, especially where sun drying of paddy is practiced and brokens tend to be high. For example, a brown rice sample obtained from a government mill (modern Satake mill, 4 sequential abrasive whiteners and no removal of brokens from bran) in the Philippines yielded 7% rice bran (based on paddy) with a 12.5% crude fat content. Closer examination of the long grain brown rice going to the whiteners showed: 35% brokens; 2% very immature kernels, hulls, and foreign matter; and 1% paddy. Based on Table III estimates, these deficiencies indicate a crude fat content penalty of 6.78% Adding the 6.78% penalty to the measured 12.5% indicates a potential crude fat content of over 19% for this rice without deficiencies. In another example, a medium grain brown rice taken from a California mill had only 2% brokens and only a trace of paddy, hulls, and other foreign matter; it yielded bran with 20% crude fat content.

A considerable portion of rice paddy is parboiled. Oil of the raw rice kernel is concentrated in the outer layers and parboiling accentuates this. Paddy kernels that have fissure or cracks and which are likely to break on milling are "repaired" by parboiling. Parboiling also increases the hardness of the kernel and increased milling pressure or time is required to remove bran. The yield of bran from parboiled rice is usually less than that from white rice and its oil content

is higher. Parboiled brans with 30% oil are not uncommon. Furthermore, parboiled rice brans produced on modern two stage rice mills consistently have high fat content, usually over 20%. Rice quality (brokens, immature kernels, etc.) and milling factors are less important in parboiled bran quality. The parboiling process inactivates lipolytic enzymes and if the parboiled bran is protected from microbial and insect infestations, it is quite resistant to FFA development.

TABLE III

Estimated Effects of Rice Quality and Milling Considerations on Oil Content of Rice Bran

| | | Effect on Rice Bran Oil Content % |
|---|---|---|
| **QUALITY FACTORS** | | |
| 1. Each 5% of broken kernels in the brown rice[a] (starchy endosperm dilution of bran) | | -0.56 |
| a. Due to abraded floury endosperm in bran | -0.15 | |
| b. Due to small brokens in bran | -0.41 | |
| 2. Each 1% of very immature paddy, hulls, or other foreign matter in brown rice going to the whiteners (hull, starchy endosperm, and foreign matter dilution of bran) | | -1.54 |
| 3. Each 1% of chalky kernels[b] (starchy endosperm dilution of bran) | | -0.15 |
| **MILLING PROCESS AND FACTORS** | | |
| 1. Rubber roll dehuller replaces disk-type dehuller[c] | | +3.0 |
| 2. Friction milling replaces abrasive milling | | +1.0 |
| 3. Multiple pass milling replaces single pass milling[d] | | +1.0 |
| 4. Bran sieving to remove brokens; for each 5% brokens removed from bran | | +0.75 |
| 5. Calcium carbonate milling aid; for each 0.5% added based on brown rice ($CaCO_3$ dilution of bran) | | -0.81 |
| 6. Each 1% of paddy in brown rice going to whiteners (hull dilution of bran) | | -0.34 |

a. Assumes 20% additional surface area when a kernel is broken and that this new area is abraded at the same rate as the kernel's outer surface. It is also assumed that 5% of broken rice will be chipped and rebroken such that it passes into the bran as small brokens. Brokens can be as high as 40 to 50% when paddy is subjected to adverse conditions near harvest and during sun drying.
b. Chalky kernels measured as a percent of milled white rice. Assumes that 10% of chalky kernel endosperm is abraded or pulverized and enters bran.
c. In addition, disk-type dehullers remove as much as 2% bran reducing the amount available for recovery from the whiteners (16).
d. Multiple pass milling provides the opportunity to select high oil content streams.

Rice Bran Collection

The need for transportation services depends on the rice bran processing system being set up and more specifically on where the rice bran stabilizer is to be located. There are three possibilities: 1) At the oil extraction plant, 2) At a location central to several or more mills, or 3) At the rice mill and serving only that mill.

1. Stabilizer located at the oil extraction plant

This situation is essentially the one confronting current producers of edible rice bran oil. In the current practice, bran is collected and the oil extracted all within one or two days of milling. In a Korean operation, 15 trucks collect bran from about 100 rice mills and deliver it to the oil extraction facility. During the summer when temperature and humidity are high, FFA content of crude oil averages 15%. During winter months, the FFA content averages 10%. In Japan, rapid rice bran collection is widely practiced for recovery of edible rice bran oil. Rice bran is collected, steam agglomerated, dried, and extracted within one or two days of milling yielding crude rice bran oil of 10 to 15% FFA content.

The salient characteristic of this current system is the daily collection of fresh rice bran from enough rice mills to provide sufficient bran for the continuous operation of the extraction facility. In the case of continuous solvent extractors, this is likely to be in the range of 20 to 200 metric tons per day.

The use of an extrusion stabilizer at the extraction plant in place of agglomerating/pelleting equipment could add some flexibility to the system. Since stabilized rice bran does not require immediate extraction, it could be placed in storage freeing up the extractor for use with other oil bearing

materials as the demand or conditions may dictate. Also, when rice bran availability is insufficient to supply the extractor capacity, bran could still be collected, stabilized, and stored until sufficient quantities were on hand for an economic run.

The transportation services required in this system are the daily or more frequent collection of rice bran from mills and its transfer to the oil extraction facility. One major rice bran oil extractor in Japan has its own truck fleet which collects rice bran from areas within 150 KM of the extraction facility. Bran is processed within 24 hours of milling and the extracted oil has 12.5% FFA in summer and less in winter. Transportation cost in 1987 was $35.71/MT rice bran collected (23). The company also obtains 30% of its bran supply from brokers at somewhat higher cost. The price of bran at large rice mills in Japan can be nearly double the price of that at small store front millers who may produce only 1 or 2 sacks of bran per day. Rice bran collection costs have not been reported for other countries. An estimate of such costs in a LDC is developed in the remainder of this section through the use of a hypothetical model.

Table IV provides the assumptions of this model. It is interesting to note that a single 100 MT/24hr solvent extraction plant requires all the rice bran from 259,200 MT of paddy in order to operate on rice bran for 180 days. In the model, this 100 MT/24hr plant serves a 10,000 square km area where rice is produced on 25% of the land in the monsoon season and 10% of the land in the dry season (irrigated). The average rice mill has a capacity of 2 MT paddy/hr and the rice bran yield is 7% of rice paddy. The average mill is assumed to operate 10 hours/day, 180 days/year, and to be 25 km from the solvent extraction plant.

The solvent extraction plant requires all the bran from 72 of these "average" mills and operates a fleet of 14 light diesel trucks to collect the bran daily from each of these 72 mills.

A World Bank computer prediction model (Brazilian data[a]) was used to help estimate the vehicle cost. Table IV, Section E provides the input data for the model. Depreciation and interest costs are $1.75/MT of rice bran collected; fuel, lubricants, tires, and maintenance including parts are $2.42/MT, and crew time labor (driver) is $1.07/MT. There is no loading cost for the bran at the mill since bran is sold f.o.b. at the mill. The unloading cost at the extraction plant is $0.54/MT ($0.50/hr for laborers). Therefore, the direct costs for rice bran collection are estimated at $5.78/MT. Adding 15% for overhead yields a total rice bran collection cost of $6.65/MT or $119,700 for one year's operation.

This cost is penalized by the underutilization (80%) of truck capacity, significant non-travel time (1 hr) of trucks during each manual loading or unloading, no back haul load, and use of the trucks for only a portion of the year. Small trucks are required by the geographic dispersion of the rice mills, the small quantity of bran available at each mill, and by limiting road conditions.

---

a. Dhareshwar, A. and Archondo, R. Vehicle operating cost prediction model with IBM PC program diskette and prediction tables. First Draft; April 9, 1986. World Bank, Transportation Department, Washington, D. C., USA.

TABLE IV

Model of Rice Bran Collection System to Supply a
100 MT/24 Hour Continuous Solvent Extraction Plant

| | |
|---|---|
| **A. Rice Production** | |
| 1. Geographic Area served by solvent extraction plant | 10,000 $km^2$ |
| 2. Area seeded in rice | |
| a. Monsoon crop | 2,500 $km^2$ |
| b. Dry season crop | 1,000 $km^2$ |
| 3. Average paddy yield | 2.8 MT/ha |
| 4. Total annual production of paddy in area | 980,000 MT |
| 5. Rice paddy entering commercial channels (80%) | 784,000 MT |
| **B. Rice Milling** | |
| 1. Average commercial rice mill capacity | 2 MT paddy/hr |
| 2. Average hours worked per day | 10 hrs. |
| 3. Average annual days worked | 180 days |
| 4. Annual amount of paddy required for average mill | 3,600 MT |
| 5. Total number of commercial mills to process commercial crop | 218 mills |
| 6 Number of average commercial mills necessary to supply 100 MT rice bran/day (7% bran yield based on paddy) | 72 mills |
| **C. Solvent Extraction Plant** | |
| 1. Days of operation on rice bran per year | 180 days |
| 2. Total bran extracted per year | 18,000 MT |
| 3. Percent of total commercial bran in area utilized | 32.8% |
| 4. Crude rice bran oil produced; 15% yield | 2,700 MT |
| **D. Rice Bran Collection System. Daily collection at selected mills.** | |
| 1. Assume average distance of rice mill from extraction plant | 25 km |

| | | |
|---|---|---|
| 2. | Hours per day of operation of light truck fleet | 12 hrs |
| 3. | Load capacity of light truck: 3.5 MT; 80% ave. utilization | 2.8 MT/load (80 sacks) |
| 4. | Assume 1-hr needed at each mill to inspect, weigh, load, and pay | 1 hr/mill |
| 5. | Assume 1-hr to unload truck at extraction plant | 1 hr |
| 6. | Assume average road speed of | 50 km/hr |
| 7. | Hours for ave. collection trip (2 mills; 50 km) | 4 hrs |
| 8. | Number of operational trucks required for 72 rice mills | 12 trucks |
| 9. | Assume truck readiness rate at | 85% |
| 10. | Number of spare trucks required to meet 85% readiness rate | 2 trucks |
| 11. | Total number of light trucks required | 14 trucks |

E. Truck Statistics and Road Conditions

| | | |
|---|---|---|
| 1. | Truck cost (light diesel truck) | $17,500/truck |
| 2. | Interest rate | 12% |
| 3. | Average annual utilization per truck | 27,000 km |
| 4. | Average service life of vehicle | 10 years |
| 5. | Diesel fuel cost per liter | $0.30/liter |
| 6. | Lubricant cost per liter | $1.43/liter |
| 7. | New tire cost | $120.00/tire |
| 8. | Crew time cost (one driver) | $0.75/hr |
| 9. | Maintenance labor cost | $0.90/hr |
| 10. | Road surface | Paved; 2-lane |
| 11. | Road conditions: | Moderate curvature and roughness; slight gradient |

2. Stabilizer at central location to several or more rice mills

This system differs from the one where the stabilizer is located at the solvent extraction plant: 1) any individual operation can be decidedly smaller, 2) stabilized rice bran is likely to be stored for a significant time, and 3) there are increased transportation costs required in that after the bran is collected and stabilized, it must be transported to the solvent extraction plant. If there were several such independent stabilizer operations supplying a solvent extraction facility, the storage time for stabilized rice bran could be significantly reduced. This would have the advantage of reduced inventories of stabilized rice bran and thus a minimizing of working capital requirements.

Two important factors regarding solvent extraction units affect the amount of stabilized rice bran that must be accumulated: 1) short extraction runs (less than 10 days) are generally not practical and 2) larger extraction units are significantly more efficient. In developing countries, commercial solvent extraction units of 50 to 100 MT/24 hours are often available with unused capacity. For a 50 MT/24 hour unit, one would need to accumulate a minimum of 500 MT of stabilized rice bran before an extraction run is likely to be considered practical.

To explore rice bran collection costs for a centrally located stabilizer system, a model is described in Table V based on the requirement of producing 500 MT of stabilized bran within 2 months. In this model, a 0.5 MT/hour extruder stabilizer serves an area within a 25 km radius that has a total of 15 commercial rice mills of 2 MT paddy/hr average capacity. The stabilizer requires the output from 9 of these mills in order to operate 24 hour/day. See Table V for a more complete description of the model.

TABLE V

Model of a Rice Bran Collection System to Supply a 0.5 MT/Hour Centrally Located Stabilizer

| | |
|---|---|
| **A. Rice Bran stabilizer** | |
| 1. Capacity, MT raw rice bran per hour | 0.5 MT/hr |
| 2. Hours of operation scheduled per day | 24 hrs |
| 3. Operating efficiency | 85% |
| 4. MT of bran required per day | 12 MT |
| 5. Yield of stabilized bran from raw bran | 94% |
| 6. Production of stabilized bran per month (6 day week) (12 MT/day) x 85% x 94% x (26 days/month) | 250 MT |
| 7. Months or days of operation per year | 7 months; 180 days |
| **B. Rice Milling** | |
| 1. Average commercial rice mill capacity | 2 MT paddy/hour |
| 2. Average hours worked per day | 10 hrs. |
| 3. Average annual days worked | 180 days |
| 4. Annual amount of paddy required for average mill | 3,600 MT |
| 5. Number of average mills needed to supply stabilizer (7% bran yield based on paddy) | 8.6 mills |
| 6. Total number of rice mills within a 25 km radius | 15 mills |
| **C. Rice Bran Collection System. Daily collection at selected mills.** | |
| 1. Assume average distance of rice mill from stabilizer | 10 km |
| 2. Hours per days of operation of truck fleet | 8 hrs. |
| 3. Load capacity of light truck is 3.5 MT; 80% average utilization | 2.8 MT/load (80 sacks) |
| 4. Assume 1-hr needed at each mill to inspect, weigh, load, and pay | 1 hr. |
| 5. Assume 1-hr to unload truck at stabilizer plant | 1 hr. |

| | | |
|---|---|---|
| 6. | Hours for average collection trip (2 mills, 20 km) | 3.5 hours |
| 7. | Number of operational trucks required for 9 mills | 2 trucks |

D. Truck Statistics and Road Conditions

| | | |
|---|---|---|
| 1. | Truck cost (light diesel truck) | $17,500/truck |
| 2. | Interest Rate | 12% |
| 3. | Average annual utilization per truck | 8,100 km |
| 4. | Average service life of vehicle | 10 years |
| 5. | Diesel fuel cost per liter | $0.30/liter |
| 6. | Lubricants cost per liter | $1.43/liter |
| 7. | New tire cost | $120.00/tire |
| 8. | Crew time cost (one driver) | $0.75/hr |
| 9. | Maintenance labor cost | $0.90/hr |
| 10. | Road surface | paved; 2-lane |
| 11. | Road conditions | Moderate curvature and roughness; slight gradient |

As in the previous rice bran collection system analysis, a World Bank prediction model was used to help estimate vehicle costs. Table V, Section D provides the input data for the World Bank model. Depreciation and interest costs are $2.01/MT of rice bran collected; fuel, lubricants, tires, and maintenance including parts are $0.88/MT; crew time labor (driver) is $0.96/MT. There is no loading cost at the mills since bran is sold f.o.b. at the mill. The unloading cost at the stabilizer plant is $0.54/MT ($0.50/hour for laborers). Therefore, the direct costs for rice bran collection at the stabilizer are estimated at $4.39/MT. Adding 15% for overhead yields a total rice bran collection cost estimate of $5.05/MT.

However, the stabilized rice bran still requires transportation to the extraction plant. Assuming the extraction plant is 100 km from the stabilizer facility, and using $1.20/20 km/MT as the transportation cost (figure taken from Enochian et al (24) and adjusted for inflation) and using a cost of $0.54/MT each to load or unload bran, the cost to move the bran from the stabilizer facility to the extraction plant is $6.66/0.94 MT stabilized bran (equivalent to 1 MT raw bran). Thus the total rice bran collection cost plus transportation of stabilized rice bran to the extraction plant is $11.71/MT raw bran under the scenario described. This is more than the $6.65/MT when the stabilizer is located at the extraction plant.

This model calls for rice bran collection once each day from each mill, the same as in the previous system where the solvent extractor collects the bran. Experience in Japan and Korea, where extractors collect the bran and extract it all within 1 or 2 days, shows that the crude rice bran oil produced usually has 10 to 15% FFA content. The current model visualizes rice bran being collected and stabilized within one day or less and thus the FFA content limited to perhaps 7 to 10% if the system works smoothly. This advantage might be lost

during storage of the stabilized bran if stabilization was not 100% complete or insect/mold infestation sets in releasing microbial lipases thus causing fat hydrolysis.

One of the problems in rice bran collection is guaranteeing that only "fresh" bran is collected. There are no rapid, on-site quality control procedures available to test the bran for freshness (low FFA content) or fat content at the time of collection. Thus other control measures are required such as random sampling of a supplier and return of samples to the laboratory for analysis. Another approach is to make the rice millers partners in the stabilization business thus giving them a financial incentive to provide fresh bran without which the business will fail. This method also discourages adulteration of the bran with hulls or ground-up hulls that dilute the oil content of bran and results in darker crude oil and a potentially more expensive bleaching operation during the refining process. Yet another approach is to collect all the bran at a mill every day thus eliminating the existence of old bran. These approaches are likely to be less than fully satisfactory. There is a definite need to develop rapid, low-cost, on-site methods to determine the content of crude fat, FFA's, and hulls in the bran. With such capability, one would also develop the relationship between bran quality and value (for oil production) so that appropriate prices could be set for the indicated bran quality.

3. Stabilizer at the Rice Mill

In this system, rice bran is taken directly from the rice milling equipment and extrusion stabilized within minutes to capture the low 2 to 3% FFA level that exists in "just milled rice bran". This, of course, requires a close match of extrusion capacity with the rate of rice bran production. Stabilized rice bran

could be stored at the rice mill until a sufficient quantity was accumulated to support an economic oil extraction run, or, it could be immediately transported to the extractor for storage at the extraction plant. Assuming a distance of 100 KM to the extraction plant and using $1.20/20 KM/MT transportation cost and $0.54/MT each to load or unload bran, the total delivery cost is $6.66/0.94 MT stabilized bran (equivalent to 1 MT raw bran).

The advantage of this system is that stabilization of bran at the low FFA level of 2 to 3% gives significantly higher yields of edible oil during refining, especially when the standard alkali refining process is used. Three percent FFA versus 13% FFA in the stabilized bran can result in an increased production of edible oil of 20%.

Rice Bran Stabilization

A number of methods have been developed to stabilize rice bran and the subject has been extensively reviewed (8, 16, 25, and 26). Only extrusion stabilization is being used to any extent commercially.

Williams and Baer (27) reported the first successful extrusion stabilization of rice bran using an Anderson 4.5 inch "pilot-scale" Expander. Rice bran at 7% FFA content was fed at 58 Kg per hour to the barrel where water and steam were injected to raise moisture content to about 25%. The injected steam plus friction of the turning screw raised the temperature to 121°C before discharge through the die. Superheated water vaporized on discharge expanding and cooling the extrudate which crumbled easily to a granular state and was further cooled and dried with heated air. When cooking temperatures in the Expander were more severe, the product occurred as a less desirable hard continuous rope. Sieve analysis showed only 12.7% of the 121°C extruded product passed a 24 mesh

screen and only 1.4% passed a 60 mesh screen. The extruded rice bran bulk density was about 0.40g per cubic cm compared to 0.35g per cubic cm for raw rice bran. The extruded rice bran was found to be stable for 3 months when held open to the air at room temperature. After one year, there was no significant increase in FFA content. A 122 cm bed of the granular product had a good hexane percolation rate of 1420 liters per square meter per minute at 60 - 65°C and oil extraction yields were equal to that from raw rice bran. Time to drain the marc (rice bran with hexane) was 1.6 minutes and residual hexane in the marc was 30%. From 1965 to 1970, Anderson International (Cleveland, Ohio) sold 4 Expanders in Brazil, Mexico, and Ecuador, and in 1980, one in Indonesia for rice bran processing but 3 were diverted to other uses and the status of 2 is unknown. Recently Anderson has sold some 8-inch Expanders for use on rice bran in India.

Sirur (28) notes that Tecnal, Sao Paulo, Brazil experimented in the 1970's with use of Expanders to replace flaking in the preparation of soybeans for oil extraction and was successful in demonstrating greatly improved efficiencies in solvent extraction (increased extraction capacity, increased oil content in the miscella, and reduced hexane in the marc which reduces disolventizing cost [b]). Tecnal began selling Expanders worldwide for this purpose and they also extended their studies in this area perfecting Expander technology for other oil bearing materials including rice bran. The Tecnal process, described in a Company brochure, consists of: rice bran cleaning; uniform feeding to the Expander; steam injection; extrusion as "small, porous, well compacted cylinders"; and drying and cooling. Stabilized bran can be stored 30 to 45 days (90 days or more have been successfully practiced in Thailand according to Tecnal). In preparation for solvent extraction, the stabilized bran is passed through an air separator to remove fines which are recycled to the Expander. Sirur, on visiting Tecnal, reported a granular extrudate of rice bran with pilot plant hexane percolation rates of 1,700 to 2,000 liters per square meter per minute

b. For discussion of extrusion preparation for solvent extraction, see references (29 and 30).

However, other Expander extruded materials such as soybeans had percolation rates 2 to 6 times greater.

Sirur (28) concluded that although the use of Expanders on rice bran has been demonstrated as early as 1959[c], the process has not caught on. He further noted that in India and China and most Far Eastern countries, large Expanders (1 to 10 MT/hour) are not suitable since rice mills are small (1 to 6 MT rice bran per day at the medium to larger mills) and dispersed. Furthermore, transportation infrastructure is inadequate to allow timely collection of rice bran for a central processing facility. On the other hand, Sorgi (31) at Tecnal reported Expanders are in use on rice bran at Tanakorn Oil Products Company and at Industrial Enterprises Company both in Thailand and at Soon Soon Oil Mills Sdn. Bhd. in Malaysia; however, no details are available.

With regard to the optimum extrusion conditions for various oil bearing materials in preparation for oil extraction, Sirur (28) reported that this information is generally being considered proprietary by Expander operating units. Density and porosity of extrudate are influenced by the material being extruded, moisture, temperature, and die diameter and thickness. A thin lands (die thickness) generally produces a softer extrudate that tends to crumble to a granular meal.

The early work on Expanders by Williams and Baer (27) led Lin and Cater (12) to test dry extrusion (low-cost extrusion cookers; LEC) for stabilizing rice bran. They used a Brady Crop Cooker and found that rice bran extruded at ambient moisture (9.3%) and 130°C or higher was fully stabilized. The extruded product was in the form of small flakes.

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c. Anderson International Corporation's first work with rice bran was actually in 1961.

Randall et al (13) found the Brady Crop Cooker stabilized rice bran at 140°C or at 130°C when the extrudate was held on a covered and insulated conveyor belt at 97 to 99°C for 3 minutes immediately after extrusion and before cooling. At 450 KG rice bran per hour feed rate and 130°C, Randall et al found the extruder energy consumption was 0.07 to 0.09 KW-Hr per KG rice bran. Extrusion at 10.4% moisture and 130°C yielded small flakes with 12% fines (through a 25 mesh screen). Adding 2% water before extrusion reduced fines to 7%. Thirty seconds of severe agitation of the flakes increased the amount of fines to 26% in the 10.4% moisture sample and to 35% in the 12.4% moisture sample. Higher extrusion temperatures increased the percent fines. Kim et al (32) found "pellets" extruded on a KIAST extruder at 130°C and 22% moisture also broke down when subjected to the agitation and abrasion typical in a RoTap sieve analysis.

Brady International, Torrance, California, the Company that manufactures the Brady Crop Cooker, has been a leader in the US in promoting commercial rice bran stabilization. The Company has formed joint ventures with other companies in the US and India and is exploring opportunities in other countries to setup and operate rice bran stabilization facilities. Brady has participated with Pacific International Rice Mills, Inc. (PIRMI), Woodland, Comet Rice Mills, Maxwell and the Rice Growers Association, all in California, in the operation of 12 or more Brady extruders. Most of the bran is being stabilized for export to Pacific Rim countries for oil recovery though a small amount manufactured at PIRMI were being sold as a food ingredient domestically. In India, Brady is participating with the Markfed Cooperative in Punjab state. As of August 1987, 12 Brady extruders had been installed at one rice mill and at one solvent extraction plant, and were processing rice bran produced on-site and collected from nearby rice mills. As of early 1989, up to 42 Brady extruders had been imported by India for rice bran stabilization. The stabilized bran is slated for use in recovery of edible grade crude rice bran oil. Indian Standards stipulate that edible grade crude rice bran oil must have less than 7% FFA content.

Even though called edible, the crude oil must be refined before consumption. In addition to manufacturing the 0.5 MT/hour extruder, Brady has now designed and built a prototype to process 60 to 200 KG rice bran per hour.

Rice Bran Industries, Santa Monica, California has a Cooperative Agreement with Farmers Rice Cooperative, Sacramento, California whereby four InstaPro-2000 extruders located at Farmers are stabilizing bran produced on-site for export.

Riviana Foods, Inc. operates a Wenger X-25 extruder in the "dry" mode at its Abbeyville, Texas rice mill, producing stabilized rice bran sold primarily to the baking industry for use in multi-grain breads. The processing temperature is 154°C. Fines are not a problem in this operation since the extrudate is milled to flour.

Rice bran stabilization costs were estimated for the Farmers Rice Cooperative operation and for an operation setup in the Philippines to demonstrate the technology and determine financial feasibility. Table VI provides information that characterizes the two systems and provides estimates for various components of rice bran stabilization cost.

In the Farmers operation, bran at 10.2% moisture is pneumatically conveyed from the large, on-site rice mill to a two ton surge tank. The bran stream is split so as to feed into 4 InstaPro-2000 extruders which in turn deposit the hot extruded bran on a central conveyor belt. The extruded bran is conveyed to a forced air cooler and finally is deposited into a bulk shipping container at 7.8% moisture. Each extruder requires a rebuilding of the barrel and screw components about every 1,000 hours at a cost of $200 per rebuild. This one maintenance requirement represents half of the total maintenance cost for the total system. No estimates are provided for overhead, building, or profit. Even

TABLE VI

Rice Bran Stabilization Costs

| Location | Developed Country [a] | LDC [b] |
|---|---|---|
| System | | |
| Plant Investment (Existing Building) | $222,000 (1986) | $46,000 (1985) |
| Extruder | 4 InstaPro-2000's | 1 Brady |
| Extruder motor | 75 HP | 100 HP |
| Plant Capacity | 2.72 MT/hour | 0.45 MT/hour |
| Operating efficiency | 100% | 80% |
| Materials Handling | Bulk | 35 KG sacks |
| Workers per Shift | 1.5 workers | 5.5 workers |
| Months Operated/Year | 12 months | 10 months |
| Hours Operated/Day | 24 hours | 10 hours |
| MT Rice Bran Processed/Year | 18,149 MT/Year | 792 MT/Year |
| Rice Bran Supply | From On-Site Rice Mill by Pneumatic Conveyor | Collected from Several Small Nearby Rice Mills |
| Commodity Cost and Other Information | | |
| Rice Bran, MT | $65/MT | $100/MT |
| Electricity, KWH | $0.07/KWH | $0.088/KWH |
| Capital, Interest Rate | 12% | 12% |
| Equipment Service Life | 10 Years | 10 Years |
| Wage & Benefit Rate/Hour | $20/Hour | $0.21 to $1.06/Hour |
| Rice Bran Stabilization Costs Per MT of Raw Rice Bran Processed | | |
| Depreciation | $1.22/MT | $5.81/MT |
| Interest, Plant Investment | $1.47/MT | $6.97/MT |
| Interest, Working Capital [c] | $0.80/MT | $1.08/MT |
| Insurance [d] | $0.12/MT | $0.58/MT |
| Power | $3.91/MT | $3.78/MT |
| Labor | $11.03/MT | $4.25/MT |
| Maintenance | $0.57/MT | $1.96/MT[e] |
| Moisture Loss | $1.56/MT (2.4% Moisture loss) | $4.00/MT (4% Moisture loss) |
| Overhead | - | - |
| Profit | - | - |
| Total | $20.68/MT | $28.43/MT |
| Total without interest | $18.41/MT | $20.38/MT |

a. System installed and operated at Sacramento, California. Stabilized rice bran is for export to Pacific Rim countries for oil recovery. Operations in 1987 were considered to be on a trial basis of the technology, markets, and financial viability.
b. System installed at Cabanatuan City, Luzon, The Philippines for demonstration and determination of financial feasibility. Intermittently operated during 1985-1986.
c. One month's supply of bran, electricity, and labour. Required working capital: Developed country system $120,902; LDC system $8,574.
d. One percent of plant investment per year.
e. Assumes 500 hours of operation before rebuild of extruder screw and die parts are required.

though only 1.5 people per shift operate the plant, labor represents over half the rice bran stabilization cost.

In the Philippines operation located at Cabanatuan City, Luzon, rice bran at 10 to 11% moisture was collected from several nearby rice mills in 35 KG polypropylene sacks. The rice mills were of 1 to 3 MT paddy per hour capacity. The rice bran was hand dumped, without sieving, into the feed hopper of the Brady extruder as required. One to two percent water was metered into the bran just as it entered the extruder. The extruder was operated at 138°C. The rice bran extruded as small flakes and the addition of water before extrusion improved flake integrity and reduced fines which can cause problems during solvent extraction of the oil. Experimental work showed that sieving the raw rice bran on an 18 to 20 mesh screen before extrusion to remove broken rice, hulls, and foreign matter (15 to 20% removed), not only increased oil content of the rice bran 1 to 2% but also improve flake integrity. Furthermore, sieved bran tolerated more water addition during extrusion which further improved flake integrity and reduced fines.

Bran exiting the extruder was immediately picked up on a covered conveyor where it was held at 93 to 97°C for 2.5 minutes before dumping into a rotating horizontal cylinder with baffles and forced air for cooling. Cooled bran was then deposited into a pack-out surge bin and was periodically bagged-off in 35 KG polypropylene sacks for later removal to the warehouse.

This system, with just one Brady extruder, required 5.5 workers per shift largely because of the manual handling of the bran in 35 KG sacks. This compares with 1.5 people per shift necessary to operate the Farmers system that has a capacity 6 times greater and 4 extruders but with bulk handling of bran.

However, because of low wage levels in the Philippines, labor costs in the Philippines was only $4.25/MT of rice bran processed compared to $11.03 for the Farmers system. Depreciation and interest costs were nearly 5 times greater for the Philippine operation because the Philippine system operated only 10 months of the year and 10 hours per day compared with full year and 24 hour per day operation at Farmers.

A major difference between the two systems which is not shown in Table VI but which greatly affects the value of the stabilized rice bran is the FFA content. The Farmers system arrests FFA content at 2 to 3% while in the Philippine system, where the rice bran is collected from several nearby mills, FFA content ran about 10%. The effect of FFA content on economics is discussed later.

Extruder wear is a factor of some uncertainty and there is a need for additional studies. Early experience in the Philippines showed that screws wore out after 50 to 100 hours before rebuild was required. However, this work was done on a V-belt drive Brady whereas all previous Bradys were direct drive units including the one used by Randall et al (13) in California where screw life was estimated at 1,000 to 2,000 hours and die parts over 500 hours. The two bearings that support the screw in the Brady are very close together and a degree of eccentric rotation was observed in the V-belt drive Brady. This factor may have caused the rapid wear problem. The V-belt drive was replaced with a direct drive and while performance seemed to improve, subsequent operations were of insufficient duration to determine wear rates of the direct drive version. For purposes of Table VI where stabilization costs are presented, 500 hours of screw life were

estimated for the Brady in the Philippines. However, rice bran available in the Philippines is significantly different than that in the USA with Philippine bran containing more hulls and foreign matter that are abrasive. Additional studies are needed to determine the effect of bran quality on extruder wear. In particular, dry extruders depend solely on frictional heat to achieve stabilization and thus abrasiveness of bran is more critical than in steam injected extruders such as the Anderson where only a portion of the heat is derived from friction.

Rice Bran Oil Extraction

Particle size is a critical issue in oil extraction. Fines reduce percolation rates in the extractor and if they become suspended in the miscella, they can cause fouling of the miscella disolventizing equipment and problems in refining further down stream. Therefore, rice bran must be agglomerated for efficient, economic oil extraction in continuous, gravity percolation type solvent extractors. This can be achieved by extrusion cooking, steam agglomeration (widely used in Japan), or pelleting (widely used in India). All these methods use cooking of the floury starch in the bran to obtain a good binding effect.

Sah (17) noted the need to maximize surface area of pellets for rapid extraction. He found pellets of 10 mm diameter and 4 mm length required 90 minutes at 68°C to extract to a 1% residual oil content compared to over 300 minutes for a 10 X 9 mm pellet. Koenig (33) reported 3 mm diameter pellets are optimum. Rao (34) noted that pellets should be flash cooled to improve porosity. The dimensions of extrusion cooked rice bran in granular or flaky form are generally smaller than pellets and oil extraction is rapid. Sayre et al (35) reported 96% of oil was extracted in a Soxhlet in 5 minutes at 60°C from extrusion stabilized rice bran. Tribelhorn et al (36) reported the percolation rate of 22%

oil/hexane miscella in a 60 cm bed of extruded rice bran was 563 liters/meter$^2$/minute, a rate suitable for commercial solvent extraction plants. Williams and Baer (26) reported a hexane percolation rate of 1,420 liters/meter$^2$/minute in a 122 cm extruded rice bran bed at 60°C indicating that there can be substantial differences among variously extruded rice brans. Suresh (37) reported that an extruded (KIAST) rice bran had a hexane percolation rate of 37.5 liters/meter$^2$/minute compared to 7.4 liters for a steamed and dried rice bran.

Pillaiyar (38) notes that parboiled rice bran (which has less starch) is more difficult to pellet but can be pelleted by using a higher temperature (84-90°C) and a minimum of 13 to 15% moisture. He found that these pellets, dried to 11% moisture, largely disintegrated in subsequent transport and resulted in poor extraction (fines reduced the percolation rate). Reduction of moisture to 8% moisture hardened the pellets sufficiently to avoid disintegration. The effect of moisture content on strength of extruded product has not been reported. Dry extruded product is usually produced at less than 8% moisture, but, if stored without protection, moisture content could increase.

Pillaiyar (38) noted that irrespective of the type of bran, presence of coarse particles such as husk and broken rice weaken the pellets. A similar phenomenon has been observed in extruded rice bran. Potential fragility of extruded rice bran dictates close attention to bran cleaning to remove coarse particles, proper extrusion conditions, and gentle handling of the extruded product to avoid formation of fines (material through a 20-25 mesh sieve). For example, use of a screw conveyor with extruded rice bran is probably inappropriate.

Extrusion stabilized rice bran produced in California and exported to Japan, Taiwan, and Korea is being commercially extracted, however, reports on the type

of extractors and performance are not publicly available. Markfed, in partnership with Brady International, is extruding and extracting rice bran in Punjab State, India. Once again, results have not been publicized. Harper et al (39) sent samples of LEC (Brady extruder) stabilized rice bran to 150 companies (23 responded) asking about the suitability of the stabilized rice bran for oil extraction. Conclusions from the survey were that rotocel-type extractors or a horizontal basket-type extractor similar to that manufactured by HLS were suitable. The HLS extractor actually dumps the bran and reforms the extraction bed during processing thus overcoming any slowdown in percolation or channeling that might develop in an undisturbed bed. Extraction with horizontal belt extractors such as Crown, DeSmet, or Troika could be a problem due to fines and testing would be required.

The steam agglomeration process increases the particle size of rice bran but the particle size produced is still quite small. The Thai Edible Oil Company, Bangkok, uses steam agglomeration and drying to prepare rice bran for oil extraction. The Company uses a "raker" at each solvent spray point to prevent fines from building up a surface barrier which would result in poor percolation and channeling (40). Miscella is filtered to remove sludge before advancing to the evaporators and is filtered again after disolventizing. Such procedures might also be used with extruded rice bran if fines were found to create difficulties.

Yoshino Seisakusho Company, Osaka, Japan (41) has described a "low temperature extraction process" for rice bran wherein pelleted rice bran is extracted in a rotary-type hexane extractor. The wax and gums are largely retained in the rice bran and as a result, conventional dewaxing is not required in the refining phase. The unit uses six sequential showers or washes of the bran, the last being pure hexane. Undoubtedly, the capacity of the extractor is significantly

reduced by the use of the low temperature compared to the traditional 60-65°C extraction process. Rao (34), who has discussed a number of operational details and potential improvements of Indian rice bran extractors, reported that a plant designed to hexane extract 100 MT of pelleted rice bran at 60°C can only handle 30 MT at 15°C. Barber and Barber (42) reported that rice bran wax is insoluble in hexane below 10°C. Though the Yoshino Process is available, it is believed that most rice bran is extracted at higher temperatures or those approaching the boiling point of hexane.

Fines, as already noted, are a problem in rice bran due to incomplete agglomeration and weakness of the formed agglomerates that leads to subsequent breakdown. These fines can reduce the percolation rate and cause channeling resulting in incomplete extraction of the oil. Fines suspended in the miscella can cause fouling in the miscella disolventizing equipment and problems in subsequent refining. If the extractor system has not been designed for rice bran or to deal with fines, it may be necessary to install filtering equipment to remove fines from the miscella before disolventizing. Too high a temperature and suspended solids in the miscella during final stripping of hexane from the crude oil can lead to darkening of oil and fixing (cannot be bleached) of color. In Japan, steam agglomerated rice is dried to 5% moisture content which "crisps" (hardens) the particles and gives good oil extraction. Recommended extraction moisture contents for extruded or pelleted rice bran were not found in the literature but current practice suggests extraction at about 8 to 10% moisture.

Hunnell has noted (43) that solvent extractors are operated at pressures less than atmospheric to avoid fire hazards with the hexane. He notes, however, that these extractors must have positive ventilation at their upper levels to avoid condensation buildup and corrosion.

Sah (17) noted that the shell and tube-type solvent vapor condensing heat exchanger is stainless steel in rice bran processing to prevent corrosion and degradation of heat transfer. FFA development during extraction is negligible (44) but crude rice bran oil emerging from the disolventizing unit is not completely stable. If it is to be stored for more than a few days before refining, it should be cleaned (filtered) and degummed immediately. Koenig (33) noted that storage of crude rice bran oil in mild steel tanks should be avoided to prevent FFA development and fixing of color. To the extent that the crude oil is to be stored at the solvent extraction plant, cleaning and degumming might be considered part of the extraction process.

Extraction yields achieved in Japan, when starting with 19% crude fat content of raw rice bran, were reported (45) as 17.5% crude oil and 76% defatted rice bran indicating a loss of 6.5% of the input material. Defatted rice bran produced from solvent extraction is a stable, free flowing product, quite light in color, having 14 to 16% protein. Feed markets, domestic and export, are available for defatted rice bran often at premium prices over unprocessed raw rice bran because of the desirable attributes described above. If produced under sanitary conditions from high quality rice bran, there is potential for use in foods, e.g., breads, crackers, and breakfast cereals. Extrusion stabilized full fat rice bran has already found markets in the USA in speciality breads and crackers.

Sah (17) has analyzed the financial and economic aspects of various sized rice bran oil extraction plants (DeSmet type) in India. The 1984 estimated processing costs for 1 MT of rice bran was $26.10 for a 50 MT/24 hour plant, $25.30 for a 100 MT/24 hour plant, and $22.53 for a 200 MT/24 hour plant. The costs

include labor, power, hexane loss (10 liters/MT rice bran processed), repairs, selling expenses, general administration, depreciation, and interest on 30 days working capital. Planned operations were for 300 days/year while actual operation were estimated at 90% or 270 days. Lal and Chandrasekaran (46) reported 1984 oil extraction cost of 350 Rupees ($31)/MT rice bran (no profit included). A custom oil extractor in California extracted 150 MT extrusion stabilized (InstaPro-2000 extruder) rice bran on a Crown Extractor in December 1986. Based on this experience, the Company quoted a price of $55/MT of input stabilized rice bran for small batches and as low as $45/MT for large processing runs (includes the extractor's margin). Enochian et al (24) reported a cost of $29.44/MT rice bran (includes a margin) for extraction plants of about 20 MT/24 hours capacity in India in 1979. Extraction cost will vary with a number of factors including size of the plant, length of the extraction run, and efficiency of the plant, e.g. some plants lose as much as 10 liters hexane/MT rice bran processed while more efficient plants may lose only 2 or 3 liter/MT. For purposes of the paper, an extraction cost of $40/MT of input stabilized rice bran is taken which includes a profit margin. The product yields of this extraction are taken as:

1. % CRBO = % Crude Oil content of Raw Rice Bran - 1.5%
2. % DRB = 100% - % CRBO - 6.5% = 93.5% - % CRBO

   where CRBO refers to Crude Rice Bran Oil

   DRB refers to Defatted Rice Bran.

Rice Bran Oil Refining

There are many processes used to refine rice bran oil and there is a constant interest in new technologies that promise to decrease the significant yield losses that typically occur in refining crude rice bran oil. Rice bran oil refining has been reviewed extensively (2, 8, 45, 47, 48, 49).

The most commonly practiced technology is referred to as "conventional alkali refining" and may entail degumming, dewaxing, alkali refining (neutralization), bleaching, deodorizing, and winterizing. This technology can produce acceptable yields of refined edible oil when the crude rice bran oil does not exceed 10 to 15% FFA. Table VII provides yield data in the practice of this technology. However, as can be seen in Table VII, this technology is not a single process that is well standardized. Not all sub-processes listed above are necessarily carried out, or followed in a particular sequence. Also, varying levels of technological sophistication can be employed. There may be numerous variations in practice as to chemical agents used in degumming, separation techniques (settling, filtering, vacuum filtering, centrifuging), processing temperatures and conditions, bleaching clay, and so forth.

One oil technologist (50) provided the following "rule of thumb" equation for estimating the yield of refined salad oil from crude rice bran oil by conventional alkali refining:

$$\% \text{ Yield of Salad Oil} = 100 - 2(\% \text{ Theoretical Gums, Moisture, and impurities} + \% \text{ Theoretical Waxes} + \% \text{ FFA in Crude Oil})$$

Using a figure of 2% for theoretical gums, moisture, and impurities and a figure of 4% for theoretical waxes, the equation becomes:

$$\% \text{ Yield of Salad Oil} = 100 - 2(6 + \% \text{ FFA}) = 88 - 2(\% \text{ FFA}).$$

This Equation is plotted in Figure 2 and shows the relationship between estimated yield of salad oil and % FFA content of the crude rice bran oil. The estimates indicated in Figure 2 are, perhaps, slightly better than practice (Table VII).

TABLE VII

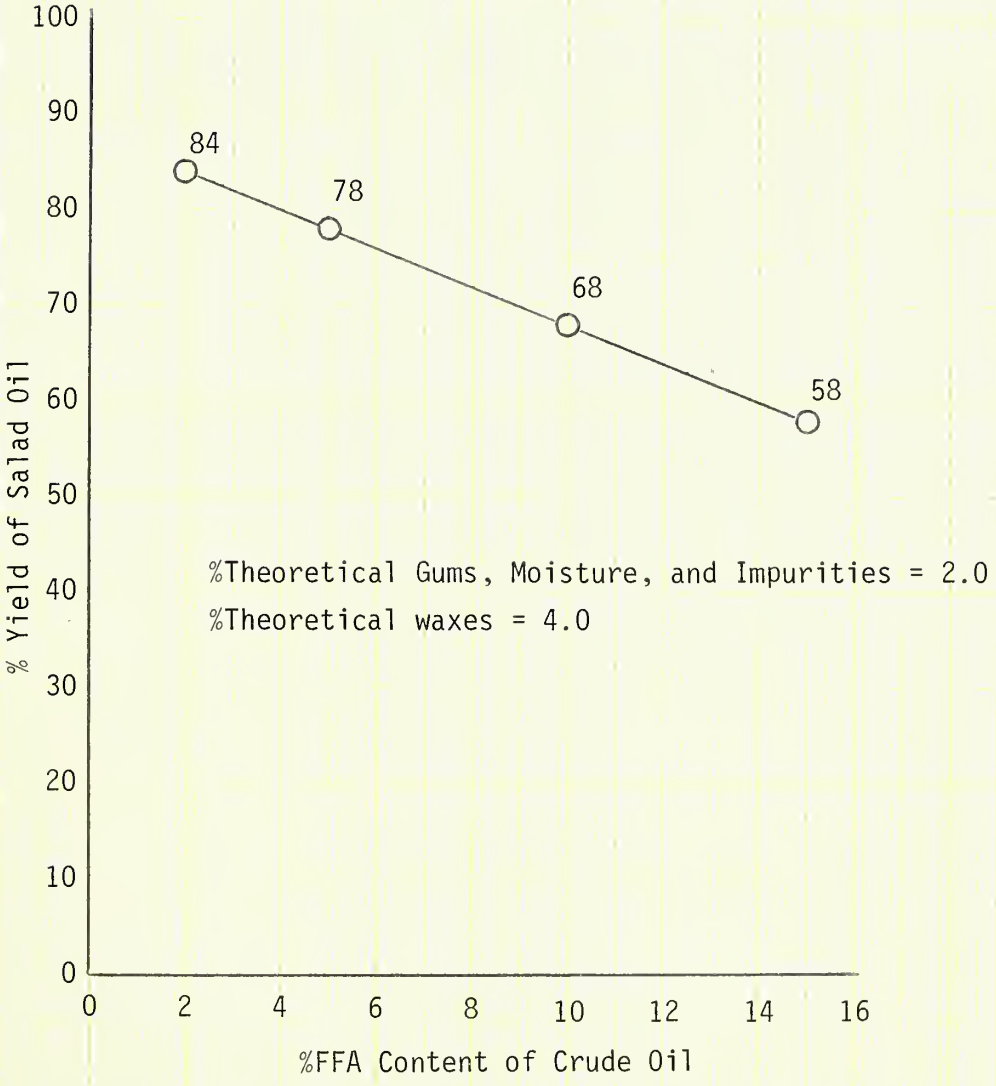
Refining Yields for Crude Rice Bran Oil Processed by Conventional Alkali Refining

| Reference | % FFA | | % Yield of Fraction Based on Crude Oil | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Crude Gums | Crude Wax | Edible Refined Oil, Non-winterized | Salad Oil, Winterized | Acidulated Oil (Dark Oil) | Stearines[a] from Winterization | Loss |
| 51 (USA) | 2.5 - 4.5 | | 0 | 6-10[b] | 80-85 | 0 | - | - | - |
| 45 (Japan) | 12.5 | | 0 | 3.6 | 67.3 | 0 | 22.9 | 0 | 6.2 |
| 52 " | 15 | | <-- 4-6 --> | | (62-66) | 54-58 | - | - | - |
| 49 " | 10 | bag | 0 | 10-12 | (63.6) | 54.1 | 18.2c | 9.5 soft | 8.2d |
| 49 " | 15 | filter dewaxing[g] | 0 | 10-12 | (55.4) | 47.1 | 26.2c | 8.3 edible oil[e] | 8.5[d] |
| 49 " | 20 | | 0 | 10-12 | (47.1) | 40.0 | 34.0c | 7.1 | 8.8[d] |
| 49 " | 10 | miscella | 0 | 5-8 | (69.6) | 66.8 | 17.6c | 2.4 soft | 8.2[d] |
| 49 " | 15 | continuous setting | 0 | 5-8 | (60.7) | 58.3 | 26.0c | 2.1 wax[f] | 8.6[d] |
| 49 " | 20 | dewaxing[h] | 0 | 5-8 | (51.9) | 49.8 | 34.3c | 1.8 | 8.9[d] |
| 49 " | 10 | miscella | 0 | 3-5 | (72.3) | 70.1 | 17.1c | 1.8 | 8.0[d] |
| 49 " | 15 | continuous vacuum | 0 | 3-5 | (63.2) | 61.3 | 25.6c | 1.6 soft wax[f] | 8.5[d] |
| 49 " | 20 | filtration dewaxing[i] | 0 | 3-5 | (54.2) | 52.6 | 34.2c | 1.3 | 8.9[d] |

a. Stearines recovered from most oilseeds contain no wax and represent a valuable refined fat product. Rice stearines contain varying levels of wax depending on the extraction and refining process and may have value as a low grade edible fat to no value (waste product). One Japanese company uses rice stearine for fuel oil (23).
b. Sodium silicate solution was used to assist wax precipitation and removal. Some gums may also have been removed.
c. Assumes 90% recovery of FFA/oil from the soap stock in the acidulation process.
d. Assumes 10% of FFA/oil in soap stock is lost during recovery of acidulated oil (dark oil). Loss also includes "scum" oil recovered during deodorization.
e. Stearine was removed from cooled oil by bag filtration.
f. Stearine (soft wax) was recovered from cooled miscella by continuous vacuum filtration.
g. Refining sequence and yield of main product at each step: Dewax 85-88%, Neutralize (100 - 2FFA - 3)%, Bleach 96.5%, Deodorize 97.3%, and Winterize 85%.
h. Refining sequence and yield of main product at each step: Dewax 90-93%, Neutralize (100 - 2FFA - 1)%, Winterize 96%, Bleach 97%, and Deodorize 97.5%.
i. Refining sequence and yield of main product at each step. Dewax 92-95%, Neutralize (100 - 2FFA)%, Winterize 97%, Bleach 97.5%, and Deodorize 97.5%.

FIGURE 2

Estimated (50) Salad Oil Yield from Crude Rice Bran Oil Using Conventional Alkali Refining by the Equation: Salad Oil Yield = 100 - 2(%Theoretical Gums, Moisture, and Impurities + %Theoretical Waxes + %FFA).



Degumming is achieved by hydrating the gums in the crude rice bran oil at 80°C with 2 to 3% water often containing a degumming agent (phosphoric acid, citric acid, nonionic surface active compounds). Another process for hydrating the gums involves steam injection of the crude oil. The hydrated, heavier gums are then removed by settling or centrifugation. In some cases, the crude oil with hydrated or "conditioned" gums goes directly to the neutralization step and the gums are removed with the soap stock by centrifugation. Separated crude gums also contain some triglyceride oil and the total degumming loss may represent as much as 10% of the crude oil if separation is by settling, less if by centrifugation. Crude gums are commonly added back to defatted rice bran or they can be dried for use in producing other products or sold for feed use.

Degumming as a separate step appears not to be practiced in Japan in conventional alkali refining (49). Instead, the gums are removed during neutralization as part of the soap stock. Perhaps the ability to forego degumming reflects a "cleaner" crude oil supplied by oil extractors.

Dewaxing may be included as a separate step before or after degumming. While degumming may be an optional step, dewaxing appears to be necessary in the best practice of crude rice bran oil refining. However, many refineries in LDC's do not have appropriate refrigeration equipment necessary for dewaxing since those plants were built to process other oilseeds that do not have waxes. In the Philippines, only degumming is carried out which may remove some wax. The major wax removal occurs during the winterization step. The result of allowing waxes to remain in the oil during neutralization and other steps is increased losses, lower quality oil (darker), and difficulties in handling the large quantity of precipitate of a "slimy" nature in the winterization step.

Dewaxing is usually accomplished by controlled cooling (5 to 20°C), allowing time for the wax to crystalize and then settling, centrifuging, or filtering cold. Chemical agents can be used to assist dewaxing, e.g. sodium silicate solution (53). Separated crude wax contains triglyceride oil and the total dewaxing loss may be as high as 10 to 12% of the crude oil if separated by settling or bag filters and as little as 6 to 10% by centrifugation.

An advantage of miscella refining is a reduced loss of oil yield during dewaxing since there is a sharper separation of the crystallized waxes. Filtering as a separation process is more feasible in miscellas due to their reduced viscosities and filter-beds loaded with wax/oil can be washed with pure hexane to reduce triglyceride oil loss. Miscella dewaxing can be practiced as a variation

of the conventional alkali refining process. The crude rice bran oil is taken up in hexane to produce miscella (40 to 60% oil) which is then cooled under controlled conditions. Time is allowed for the waxes to crystallize and they are then separated from the hexane/oil mixture. The hexane/oil is disolventized and the dewaxed oil proceeds to the neutralization step. Miscella winterization can also be done which results in higher yields of salad oil. Crude wax recovered by miscella dewaxing is an excellent material for further processing to recover a refined wax.

Separate removal of waxes before neutralization results in less stearines in the winterization step and the stearines are more easily removed (filtered). If initial dewaxing is good, then there is the possibility of bypassing the winterization step altogether especially if a cooking oil is to be the final product.

Newer refining technologies include miscella solvent (hexane) alkali refining, miscella binary solvent (hexane and alcohol) alkali refining, and physical refining (molecular distillation of FFA's under high vacuum and temperature). These technologies have been reported to reduce the loss in edible oil yield and to be practicable even when FFA levels in the crude rice bran oil exceed 15%. The miscella processes have their major benefit in reducing the loss of triglyceride oil entrained in the soap stock thus improving yields of edible, refined oil. In the case of physical refining, there is no soap stock (only distilled FFA's) thus no loss of triglyceride oil and refined oil yields are higher. As already noted, miscella refining plants are more expensive due to the explosion (fire) proof equipment required. Physical refining plants may be as much as 22% less expensive than conventional alkali plants and the technology is often considered the technology of the future for refining crude rice bran oil. Physical

refining requires that the crude oil be well degummed, dewaxed, and bleached before applying the high temperature and vacuum distillation process. Two Japanese firms employing physical refining utilize crude rice bran oil extracted at 18°C which minimizes its wax content.

If a rice bran oil project includes the building of a new refinery, certainly one would want to consider these newer refining technologies. On the other hand, if one is depending on existing refineries, especially in LDC's, to process the crude oil, it is most likely to be based on conventional alkali refining and thus restricted to the type of yields shown in Table VII. The yields depicted in Table VII are based on conventional alkali refineries well tuned for work on rice bran oil. Plants built to operate on soy, peanut or certain other oils may not be adequate without modifications or additional equipment and may suffer higher yield losses of both refined edible oil and by-products (acidulated oil, stearines, waxes).

The value of crude rice bran oil depends heavily on the yields of refined oil obtainable from it. The entrepreneur considering the rice bran oil business must evaluate carefully the oil refining component. The type oil refinery, its size, and its condition are important issues, and, along with FFA level of the crude oil, will determine the yield of refined, edible oil achieved. Furthermore, the refining plant will determine if certain by-products can be recovered. Soap stock is a waste effluent unless the refinery has the capability to acid treat it and produce acidulated oil. By-products recovered and marketed forego waste disposal cost and provide a value that helps offset the cost of the refined, edible oil and thus improves competitiveness with other edible oils.

One of the critical processes in refining oils is the removal of color. Dark oils do not market well. Refined rice bran oils can be and are produced that are nearly colorless. However, dark yellow/brown colors can be "fixed" in rice bran oil such that they cannot be bleached. Information is fragmented and incomplete as to how colors are fixed in the oil. The following treatments or conditions have been reported or suggested as causing darkening of the oil: high temperature treatment of rice bran including parboiling and various rice bran stabilization processes; storage of bran especially under poor conditions; high temperature treatment of crude oil (presence of gums are implicated); storage of crude rice bran oil especially if high in FFA's; and oxidation of the oil particularly in the presence of iron or copper. Even if the darkened oil can be bleached, it is desirable to avoid darkening since more bleaching clay/charcoal is likely to be required with concommitant higher processing costs. Furthermore, there will be an increased loss of triglyceride oil in the spent bleaching clays. Sayre et al (35) refined crude rice bran oil in the laboratory which was extracted from extrusion stabilized (130°C) rice bran and found the oil could be bleached using 6% activated clay. A typical level used commercially in Japan, where rice bran is treated with minimal heat, is 2.6% activated clay (45). While this is an indication that extrusion stabilization causes increased oil color, adequate published information is lacking to ascertain this conclusively.

Enochian et al (24) reported a refining cost, including profit margin, of $102.40/MT crude vegetable oil in India in 1980. Custom refining in 1988 in the USA is in the area of $0.045 - 0.055/lb. Winterizing adds about $0.005/lb making the total refining cost between $0.05 - 0.06/lb or $110 - 132/MT. The mid range figure of $121/MT is used in later sections of this report as the turnkey cost of refining crude rice bran oil (includes a profit margin).

By-products produced during refining could be used as an offset against the refining cost and thus the final cost of the refined edible oil. Acidulated oil, the major by-product, markets at about half the price of refined salad oil in the USA where feed uses of acidulated oils are common. The value of acidulated oil is adjusted for the Total Fatty Acid (TFA) content. Stearines (saturated fats) as obtained from non-wax containing oils are considered as part of the refined oil yield and have a value similar to the refined oil. Stearines produced from rice bran oil (rice bran oil has 14 - 21% saturated fatty acids (52)) will vary tremendously in quality depending on the efficiency of dewaxing treatments prior to winterizing, if any. Stearines with a high wax content would be considered a by-product whose value would depend on use. For feed, one might assume the same value as acidulated oils. Since a high wax content stearine would have a low TFA content, its value per lb would be less than acidulated oils that have higher TFA's. If there is a wax refining capability, the stearines from rice bran oil may be more valuable.

Bran to Oil - Financial Feasibility

The basis for analyzing financial aspects of a bran to oil project has been established in the earlier sections of this report. Table VIII calls on this information and describes a likely material balance and cost scenario when rice bran is processed in a LDC, either through a system that utilizes stabilization at the rice mill or at a central location with rice bran being collected from several surrounding mills.

A stabilization cost of $17.46/MT (Table VI; interest on working capital, insurance, power, labor, maintenance, and depreciation) is used in Table VIII and is based on a LDC system that processes 0.45 MT rice bran per hour and works 10-months a year, 5 days/week, 10 hours/day and operates at 80% efficiency.

Annual rice bran stabilized is 792 MT. An additional charge of $4.00/MT of rice bran processed yields a total stabilization cost of $21.46/MT and allows the stabilization operation to achieve a 20% discounted internal rate of return over 10 years. Costs for transportation, oil extraction, and refining are the cost for custom service and include normal margins. A low level of refining technology (conventional alkali refining; bag filter system for dewaxing and winterizing -- see Table VII) is assumed which results in large refining losses. This level of refining technology is what is likely to be available in a LDC whose major food oils are other than rice bran oil. Rice bran oil is more difficult to refine and has some special requirements, especially dewaxing.

TABLE VIII

Projected Cost of Rice Bran Oil (in Bulk at the Oil Refinery) Extracted From Stabilized Rice Bran.

| Step or Activity in the Rice Bran (RB) To Oil Process | Stabilizer at the Rice Mill | | Central Stabilizer | |
|---|---|---|---|---|
| | Material Balance, MT | Product Cost + Value Added, $ (Process/Activity Cost, $) | Material Balance MT | Product Cost + Value Added, $ (Process/Activity Cost, $) |
| RB at the Rice Mill | 100 | 10,000 = $100/MT RB | 105.26 | 10,526 = $100/MT RB |
| Transportation & Handling | - | - | 105.26 | (532[1]) |
| RB at the Stabilizer | 100 | 10,000 = $100/MT RB | 100[2] | 11,058 = $110.58/MT RB |
| Stabilization[3] | 100 | (2,146) | | (2,146) |
| Stabilized Rice Bran (SRB) | 96[4] | 12,146 = $126.52/MT SRB | 96[5] | 13,204 = $137.54/MT SRB |
| Transportation & Handling[6] | 96 | (680) | 96 | (680) |
| SRB at Oil Extraction Plant | 94.08 | 12,826 = $136.33/MT SRB | 94.08 | 13,884 = $147.58/MT SRB |
| Extraction[7] | 94.08 | (3,763) | 94.08 | (3,763) |
| Crude Rice Bran Oil (CRBO) | 17.4048 | 9,533 = $547.22/MT CRBO | 17.4048 | 10,591 = $608.51/MT CRBO |
| Defatted Rice Bran (DRB)[8] | 70.56 | 7,056 = $100/MT DRB | 70.56 | 7,056 = $100.00/MT DRB |
| Transportation & Handling CRBO[9] | 17.4048 | (104) | 17.4048 | (104) |
| CRBO at the Refinery | 17.4048 | 9,637 = $553.70/MT CRBO | 17.4048 | 10,695 = $614.49/MT CRBO |
| Refining[10] | 17.4048 | (2,106) | 17.4048 | (2,106) |
| Refinery Loss, 7.7 and 8.2% resp. | 1.3369 | 0 = 0.00/MT Loss | 1.4272 | 0 = $ 0.00/MT Loss |
| Crude Wax (CW), 10% | 1.7405 | 174 = $100.00/MT CW | 1.7405 | 174 = $100.00/MT CW |
| Acidulated Oil (ARBO), 7.1 & 18.1% resp. | 1.2406 | 372 = $300.00/MT ARBO | 3.1677 | 950 = $300.00/MT ARBO |
| Stearine/wax (SW), 11.3 & 9.5% resp. | 1.9631 | 589 = $300.00/MT SW | 1.6535 | 496 = $300.00/MT SW |
| Salad Oil, 63.9% and 54.1% resp. | 11.1238 | 10,608 = $953.63/MT Salad Oil | 9.4160 | 11,181 = $1,187.45/MT Salad Oil |

- RB = Rice Bran; SRB = Stabilized Rice Bran; CRBO = Crude Rice Bran Oil; DRB = Defatted Rice Bran

CW = Crude Wax; ARBO = Acidnated Rice Bran Oil; SW = Sterine/Wax

- See next page for numbered footnotes.

Footnotes:

1. Shrinkage during rice bran collection in sacks is 5% (23).

2. Central Stabilizer model page 21. $5.05/MT

3. $21.46/MT; no interest on plant investment and does not include 4% moisture loss which is accounted for in the "Material Balance" column. Includes $4/MT profit margin which yields a 20% Discounted Internal Rate of Return (IRR) over 10 years. LDC Model, Table VI. Does not include a cost for land or building.

4. Loss during stabilization is 4% and is mostly water. Free Fatty Acid (FFA) content of oil is 3.0%

5. Loss during stabilization is 4% and is mostly water. FFA content of oil is 10%.

6. Transported in sacks. Transportation and handling cost is $7.08/MT SRB which is based on 100 Km distance from the stabilizer to the oil extraction plant. Shrinkage is 2% during handling and transportation.

7. Stabilized Rice Bran (SRB) has 20% crude oil content. Residual oil content in defatted rice bran in 1.5%. Material loss in extraction is 6.5%. Extraction cost is $40/MT SRB (see page 35 and 36).

8. Defatted rice bran (DRB) value f.o.b. at the oil extraction plant is estimated to be the same as raw full-fat rice bran or $100/MT. Crude rice bran oil (CRBO) carries the remainder of the cost.

9. $1.20/MT/20Km. Refinery is 100 Km from the oil extraction plant.

10. Refining cost is $121/MT CRBO (see page 44). Refining yields are based on Reference (49) using bag filter dewaxing and winterizing (low technology; see Table VII). Miscella dewaxing equipment and solvent recovery equipment are generally not available at oil refineries in LDC's. To achieve the better yields of salad oil possible with miscella dewaxing and winterizing (see Table VII) would require refinery plant investment.

When the stabilizer is positioned at the rice mill, Table VIII indicates the f.o.b. price of bulk salad oil must be $953.63/MT for the operation to meet all costs and normal margins and includes credits for defatted rice bran ($100/MT), acidulated oil ($300/MT), crude wax ($100/MT), and stearine/wax ($300/MT). For a centrally positioned stabilizer, salad oil cost increases about 24.5% to $1,187.45/MT. This increase is due to the cost of rice bran collection and the increased FFA level in the stabilized rice bran due to the delay between rice milling and stabilization.

Using Table VIII, one can apportion the cost of salad oil and other oil by-products as shown in Table IX. The largest cost component is extraction at about 30% of total costs. The remaining components in order of their cost are: 1) cost of rice bran less credit for defatted rice bran, 2) stabilization, 3) refining, and 4) transportation.

TABLE IX

Ranking of the Cost Components of Edible Rice Bran Oil Manufacture

| Cost Component | Rank | Stabilizer at the Mill | | Central Stabilizer | |
|---|---|---|---|---|---|
| | | $/MT Raw Rice Bran | % of Total Cost | $/MT Raw Rice Bran | % of Total Cost |
| Extraction | 1 | 37.63 | 32.0 | 35.75[1]/ | 29.0 |
| Rice bran less credit for defatted rice bran | 2 | 29.44 | 25.1 | 34.70 | 28.1 |
| Rice bran stabilization | 3 | 21.46 | 18.3 | 20.39[1]/ | 16.5 |
| Refining | 4 | 21.06 | 17.9 | 20.01[1]/ | 16.2 |
| Transportation | 5 | 7.84 | 6.7 | 12.50 | 10.2 |

1. These costs are 95% of those for the situation where the stabilizer is located at the rice mill because 5% of rice bran is lost during collection.

Figure 3 demonstrates the effect of FFA level of stabilized rice bran on the cost of salad oil. The yield of crude oil is not affected by FFA level but the yield of salad oil from the crude oil is greatly affected. For the low level refining technology (top curve; Figure 3), the cost of salad oil increases from $953/MT at 3% FFA to $1,075/MT at 10% FFA or a 12.8% increase. The use of miscella dewaxing and miscella winterizing (conventional alkali neutralization) greatly improves refining yields as can be seen in the lower curve in Figure 2. At 3% FFA, the improved refining process lowers cost of salad oil from $953/MT to $795/MT or a 16.6% reduction (assumes no overall change in the $121/MT crude oil refining cost).

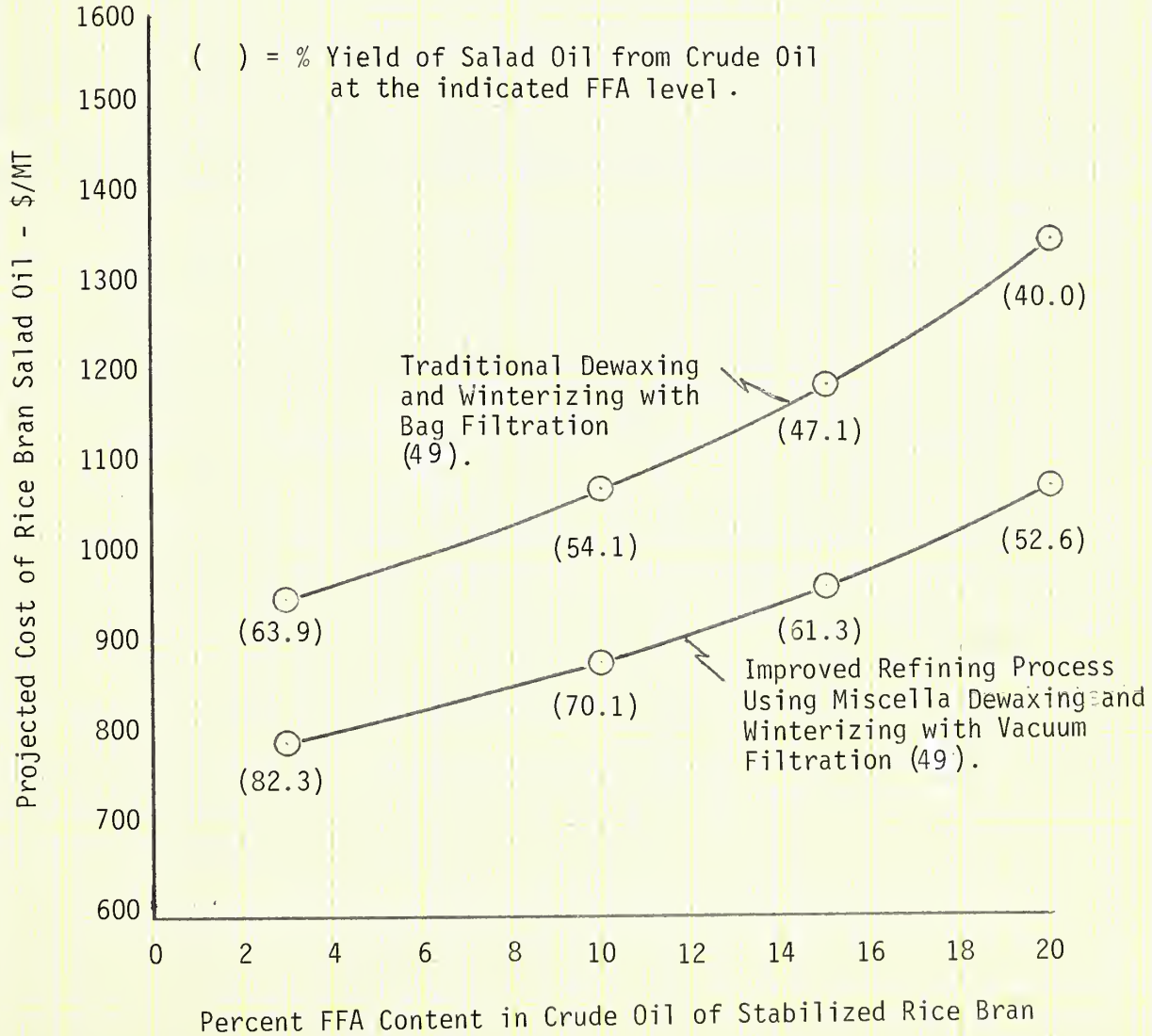
Since a value can be placed on any particular FFA content in terms of the price of salad oil (Figure 3), one is able to calculate how much money can be spent on stabilization to avoid a FFA penalty. The cost of allowing FFA's to increase from 3% to 10% (upper curve) is $1,075 -$953 = $122/MT salad oil. This $122/MT salad oil is equivalent to spending $13.57/MT rice bran on stabilization. The stabilization cost used here is $21.46/MT rice bran and thus it is (initially) concluded that it is cheaper to let the FFA's rise to 10% if the oil can then be extracted at that level and there is zero cost for stabilization. However, while there would not be a stabilization cost per se, there would be a pelletization cost (perhaps $10/MT) which is not necessary when rice bran is extrusion stabilized. Extrusion stabilization not only arrests FFA development but it also agglomerates the rice bran into flakes or granules suitable for percolation extraction making pelletization unnecessary. The net result is that there is $13.57 + $10.00 = $23.57/MT rice bran available for stabilization such that the price of salad oil would equal or be less than that achieved by extracting 10%

FIGURE 3

Effect of FFA Content of Crude Oil in Stabilized Rice Bran on Projected Cost of Rice Bran Salad Oil by Two Refining Processes Both of Which Use Conventional Alkali Neutralization.

Conditions

1. Rice bran cost and defatted rice bran price is $100/MT.
2. Based on Table VIII as to costs of transportation, stabilization, extraction, and refining and prices of oil by-products except stearine/wax from miscella winterizing which is taken at $100/MT.
3. Refining yields are according to reference (49) and are recorded in Table VII of this report.
4. Crude oil content of the stabilized rice bran is 20%.
5. Stabilizer is at the rice mill.



FFA rice bran as is now commonly done. Since the stabilization cost estimate is $21.46/MT, there is a slight cost advantage to stabilization, but furthermore, the yield of edible oil would be 18.8% greater. Stabilization at the rice mill would also increase the availability of suitable rice bran for extraction because in many cases it is just not possible or feasible to transport fresh bran to the oil extraction plant rapidly enough (within 1 or 2 days of milling) to "capture" a 10% FFA level. (Rice bran collection costs, that is, fresh bran from the rice mill to the oil extraction plant, are assumed to be about the same as the cost to transport stabilized rice bran from the rice mills to the oil extraction plant.)

The effect of rice bran stabilization cost on the cost of salad oil is shown in Figure 4. For the situation where the stabilizer is positioned at the rice mill (lower curve; Figure 4), the cost of salad oil may be expressed by the equation:

Salad oil cost/MT = 9 (Stabilization cost of rice bran/MT) + $761.

For a centrally positioned stabilizer, the equation is:

Salad oil cost/MT = 10.65 (Stabilization cost of rice bran/MT) + $959.

Oil content of rice bran is a very important determinant of salad oil cost as can be seen in Figure 5. For the case where the stabilizer is positioned at the rice mill, the increased cost of salad oil obtained from 20% oil content bran versus 25% oil content bran is $151/MT but increased salad oil cost from 15% oil content bran versus 20% oil content bran is $263/MT. Figure 5 shows the importance of efforts to obtain high oil content bran.

FIGURE 4

Effect of Rice Bran Stabilization Cost
on Cost of Rice Bran Salad Oil.

Conditions

1. Rice bran and defatted rice bran are $100/MT.
2. Based on Table VIII as to material balances and costs of transportation, extraction and refining.
3. Prices for crude wax, acidulated oil, and stearines/wax are the same as in Table VIII.
4. Crude oil content of stabilized rice bran is 20%.

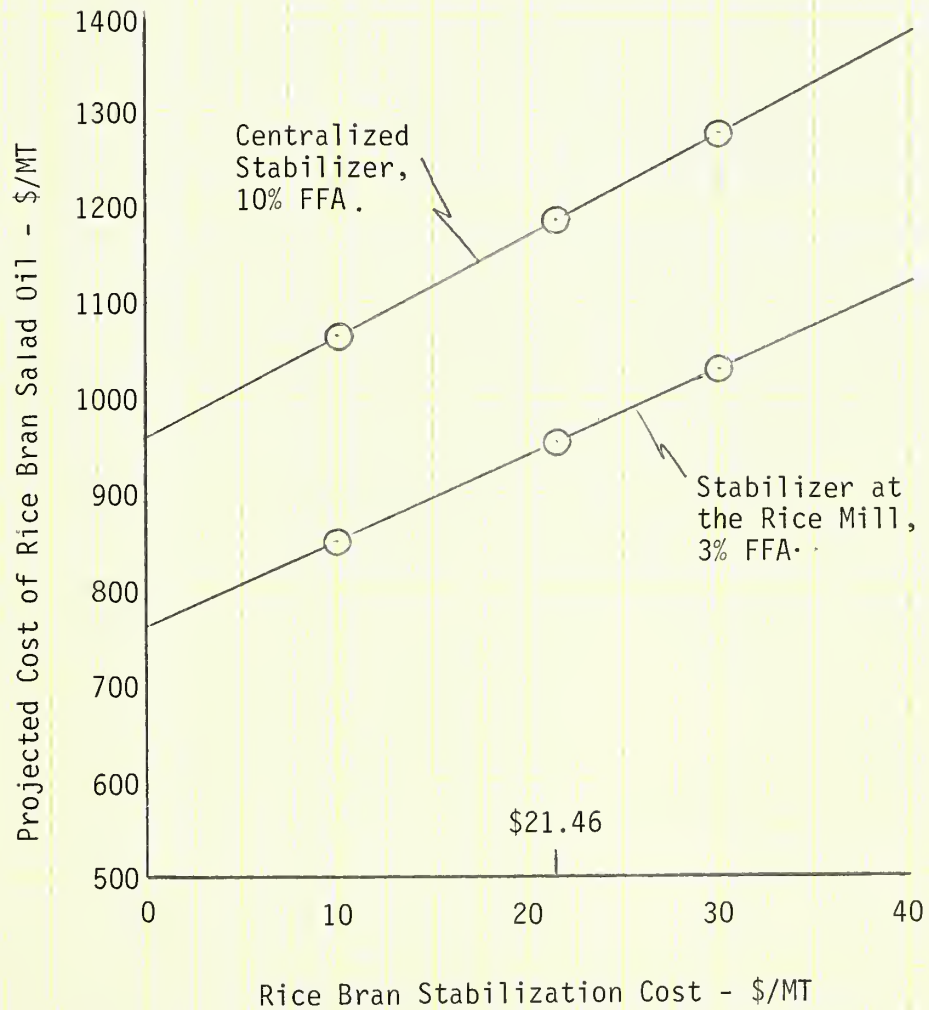
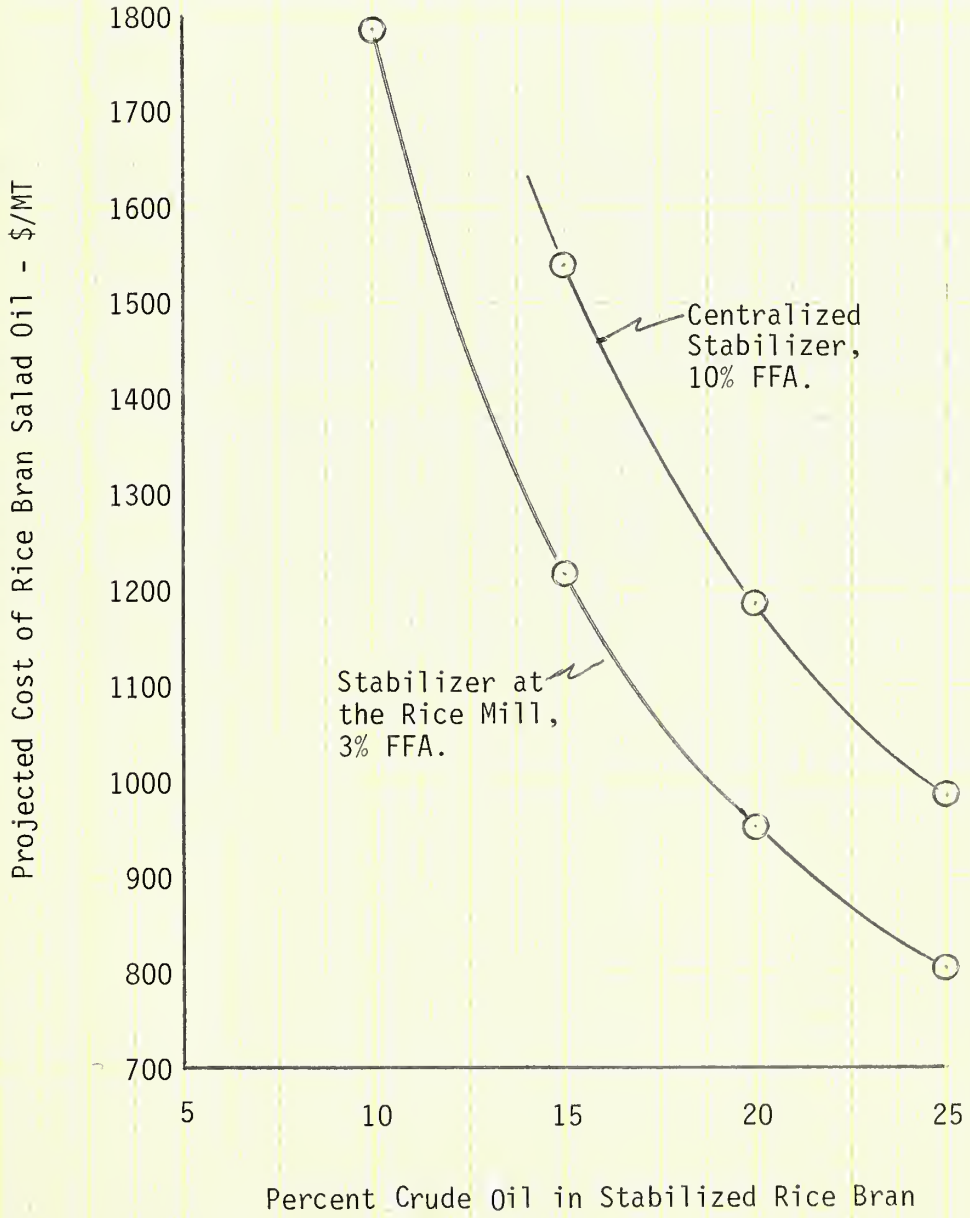


FIGURE 5

Effect of Crude Oil Content of Stabilized Rice Bran on Projected Cost of Rice Bran Salad Oil.

Conditions

1. Rice bran cost and defatted rice bran price is $100/MT.
2. Based on Table VIII as to costs for transportation, stabilization, extraction, and refining and prices of oil by-products.



The cost of rice bran does significantly affect the cost of salad oil as shown in Figure 6. For the situation where the stabilizer is located at the rice mill, an increase of $50/MT in the cost of fresh bran raises the cost of salad oil by $132/MT. The data for Figure 6 assumes that the defatted rice bran produced will be sold at the same price as the fresh bran was purchased. If a greater or lesser price is obtained for the defatted rice bran, there is a strong effect on salad oil cost as demonstrated in Figure 7. This effect points out the desirability of placing significant marketing effort on the defatted rice bran. In many countries, there are large swings in the price of rice bran over the year with the price being low during and after harvest. Storing defatted rice bran, which is very stable and amenable to bulk handling, for sale in the "off-season" when bran is scarce could be a useful strategy to obtain a better price for the defatted rice bran. For the situation where the stabilizer is located at the rice mill, an increase of $50/MT of defatted rice bran translates into a cost reduction of $317/MT salad oil. The average 1986-87 and 1987-88 export prices of defatted rice bran, f.o.b. India were $66/MT and $61/MT respectively. The Public ledger (August 13, 1988) listed defatted rice bran from India at $121/MT f.o.b. Liverpool, UK.

FIGURE 6

Effect of Rice Bran Cost on Projected Cost of Rice Bran Salad Oil

Conditions

1. Defatted rice bran is sold at the purchase price of raw rice bran per MT.
2. Based on Table VIII as to material balances and costs of transportation, stabilization, extraction, and refining, and prices of oil by-products.
3. Crude oil content of stabilized rice bran is 20%.

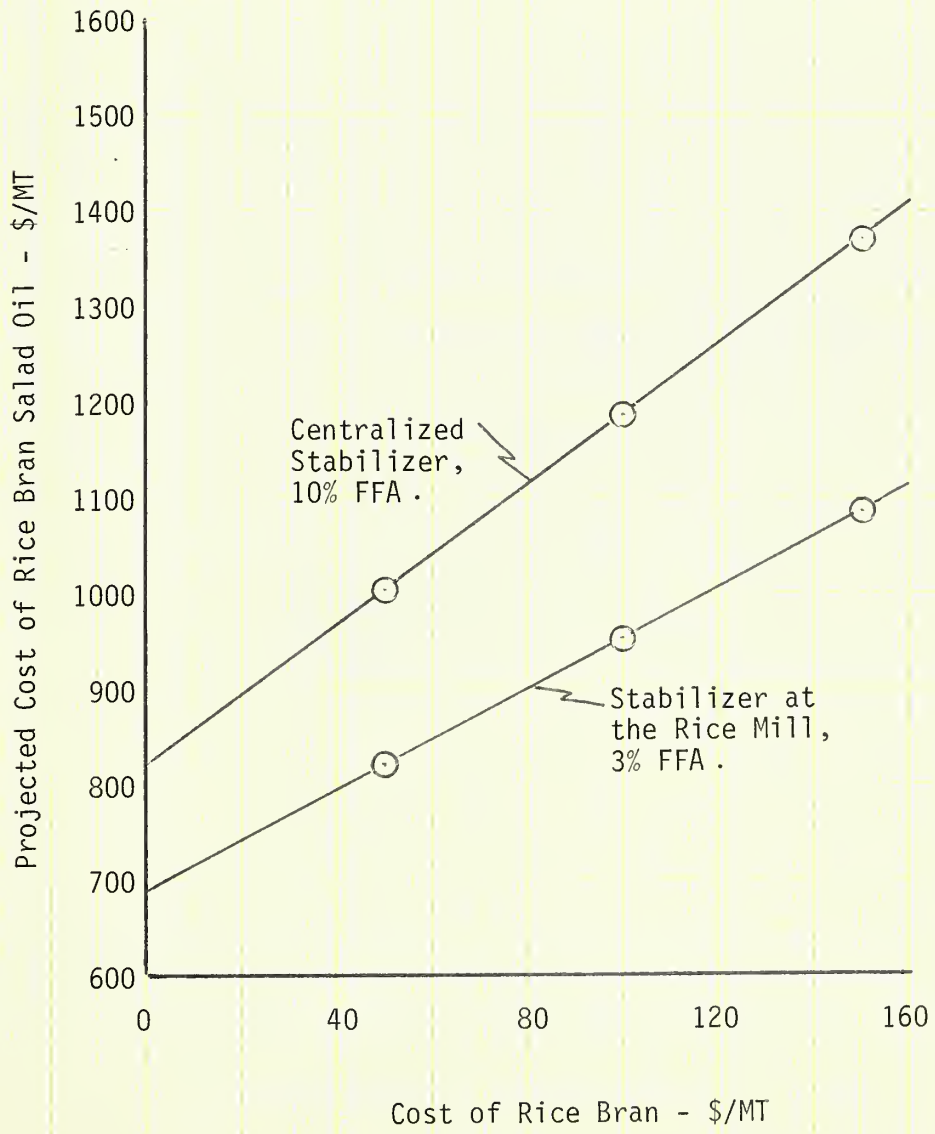
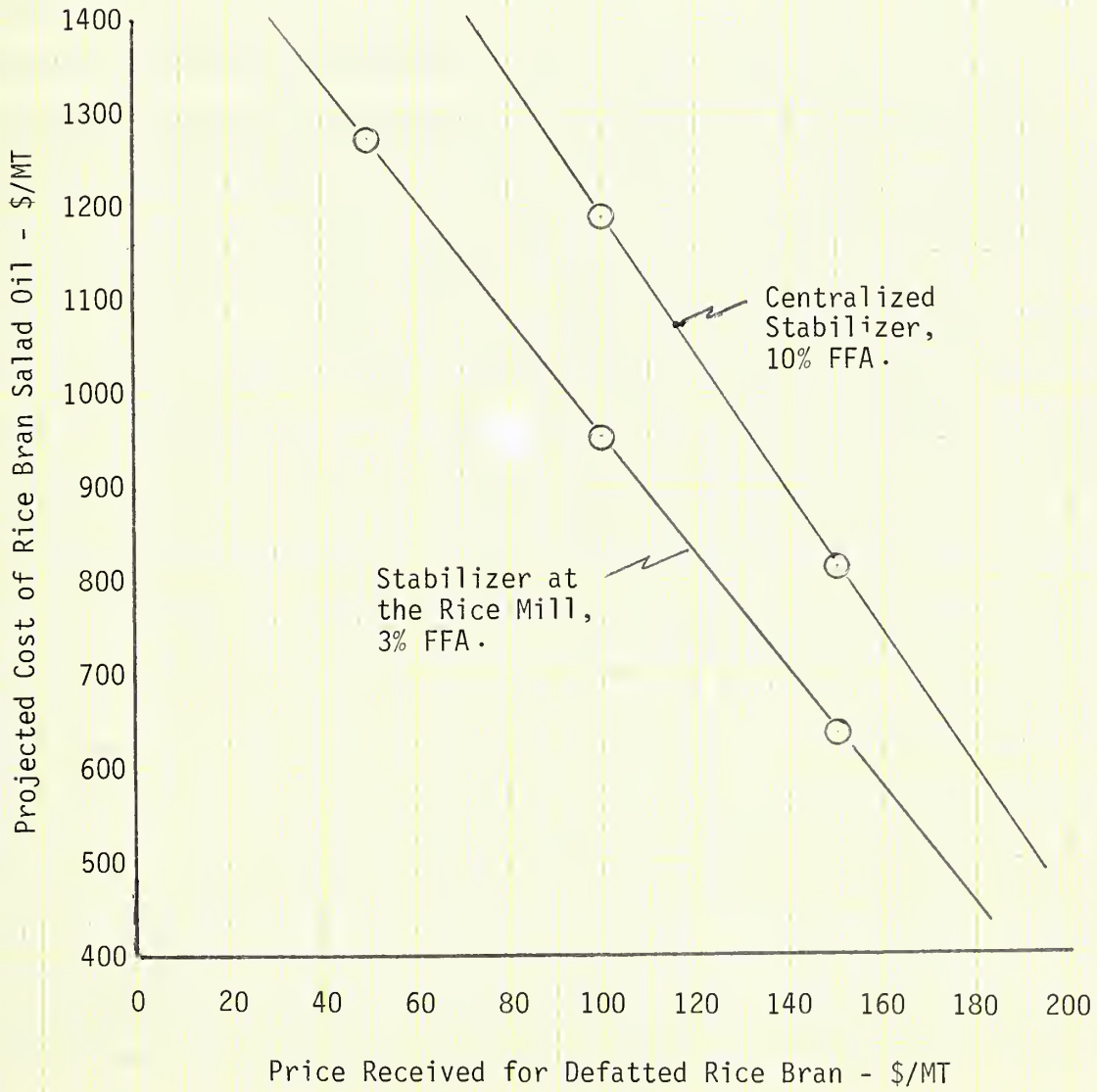


FIGURE 7

Effect of Defatted Rice Bran Price on Projected Cost of Rice Bran Salad Oil.

Conditions

1. Rice bran cost is $100/MT.
2. Based on Table VIII as to material balance and costs of transportation, stabilization, extraction, and refining and prices of crude wax, acidulated oil, and stearine/wax.
3. Crude oil content of stabilized rice bran is 20%.



If one could determine a price for rice bran salad oil that is attractive to the market, then one would be able to make some calculations based the on information available in this report that would lead to a prediction of financial feasibility. Any such prediction will be, of course, based on the several assumptions previously described.

In March 1988, one Indian company was reported (54) to be purchasing rice bran at $173/MT, stabilizing the bran on Brady extruders by dry extrusion at $69/MT, and selling defatted rice bran at $77/MT and crude rice bran oil at $1,231/MT. At these reported figures, the company's costs were $1,366/MT crude oil and thus they were losing $135/MT crude oil. Part of the high cost of rice bran stabilization was reported to be the wear out of extruder screws and die parts every 72 hours. The Brady Company, a participant in the Indian venture, indicated wear-out of rotors after 100 MT of rice bran processed but noted that the bran contained 27-37% hulls. Brady now uses a harder metal in manufacturing rotors and claims a rotor life of 400 MT of rice bran processed or 800 hours (55). The question of abrasiveness of rice bran in LDC's has not been adequately studied. Experience in the USA suggests abrasiveness is manageable with screws and die parts lasting at least 500 hours with reports of 1,000 hours or more being made. The yield of crude oil obtained by the Indian company was reported as 16.7% based on the rice bran. The cost of $173/MT rice bran is far higher than that in most countries where it generally ranges between 60 to $110/MT. The selling price of $1,231/MT crude oil translates into a price of $2,145/MT edible rice bran salad oil (based on the ratios and refining method described in Table VIII for the situation where the stabilizer is located at the rice mill). Salad oil at $2,145/MT bulk f.o.b. the refinery is much nigher than the world prices for any of the major edible oils. The Indian situation is particularly unique and

is being driven by government incentives, scarcity of other suitable oilseed stocks, significant competition among oilseed extractors for good quality rice bran, and a one million MT plus deficit of oils in the Indian market. The Indian situation, however, points out how greatly conditions and prices in LDC's can deviate from "World" conditions and prices.

July 1988 World prices, f.o.b. oil extraction facilities or ports for bulk oil, were historically high. Palm oil price was $472/MT, crude soybean oil from $517 to $654/MT, crude rapeseed oil 550/MT, crude sunflower oil $622 to $692/MT, and crude peanut oil $769 to $860/MT. Refined oils (at wholesale bulk) are $100 to $200/MT more than the crude oils from which they are manufactured. Thus the price range of these major edible oils in the July 1988 timeframe was in the order of $600 to $1,000/MT. As noted in Table VIII, refined rice bran salad oil was estimated at $953/MT (stabilizer at the rice mill) which is at the upper end of the World prices of other refined edible oils.

In Japan, rice bran oil is associated with good health and longevity. These effects are believed to be due to the oryzanol content of rice bran oil. In fact substantial effort has been made in Japan to extract and purify this phenolic material from rice bran for direct marketing in the health products market. This attribute of rice bran oil results in a higher valuation being placed upon it. However, no other aspects of rice bran oil are apparent that are not also provided by other major oils. Accordingly, rice bran oil must compete head on with other oils which means a price range similar to the other oils. That rice bran oil cost is at the upper end of the price range for other oils suggests difficulties in marketing it. However, rice bran oil production in an oil short country might be encouraged by the fact that imported oil will also include a transportation cost thus making local rice bran oil more competitive.

## Conclusions

The current paper brings together a considerable amount of information about rice bran and its handling and processing for edible oil production, but it is far from complete. An entrepreneur would need to collect pertinent information for the proposed location of business and verify a number of assumptions made here, e.g., those used in Table VIII. Certain information will only be obtainable through production trials, e.g., what yield and quality of edible oil can be expected from a specific oil extraction/oil refining system?

Rice bran in developing countries tends to have significantly lower oil content than rice bran in the United States. This is due to the use of sun drying paddy on the "ground" which increases moisture stressed/broken kernels and leads to higher levels of foreign matter contamination including sand and dirt. Paddy cleaning, grading, and dehulling tends to be less rigorous in LDC's and thus more foreign matter, immature kernels, broken kernels, unhulled paddy, and hulls tend to enter the brown rice and subsequently the rice bran thereby diluting bran oil content and making it more abrasive. Upgrading bran quality is likely to be an important aspect of any rice bran oil project in an LDC. It is uncertain how important abrasiveness of rice bran in LDC's is to extruder wear and thus the cost of extrusion stabilization. There are indications that extruder wear can be intolerably high in LDC's.

Extrusion stabilization is successfully practiced in the United States and the development of Free Fatty Acids (FFA's) is essentially completely inhibited. However, stabilized rice bran infested with insects and displaying microbial activity will again become unstable and show FFA development. High humidity, high temperature, and limited insect controls in many LDC's probably limit the

The storage life of stabilized rice bran to 1 to 3 months (porous bags). Because FFA development in rice bran is most rapid immediately after milling, stabilizers are best located at the rice mill. Centrally located stabilizers will suffer two additional costs; higher FFA levels (delay in getting the rice bran stabilized) and rice bran collection. There is some uncertainty as to the effect of the high temperatures used in extrusion stabilization on oil darkening. Extrusion stabilization may lead to a greater requirement for bleaching agents during refining or even a darker oil (non-bleachable).

While oil extraction is the largest cost in production of rice bran oil, it appears to present the least problems. Rice bran must be agglomerated for use in gravity-type percolation extractors. Extrusion stabilization accomplishes this though there is some worry about the amount of "fines" (through a 25 mesh sieve) in the extrusion stabilized bran and the fragility of the stabilized bran.

Rice bran oil has been reported to be the most difficult of the oils to refine. There are newer refining methods which greatly improve yield of edible refined oil from crude rice bran oil, but such processes are not generally available in LDC's. Refineries in LDC's tend to be "conventional alkali refiners that have limited capabilities to deal with the high levels of gums, waxes, and free fatty acids present in crude rice bran oil. The result is poor yields of edible oil and little or no recovery of by-products.

The financial feasibility study prepared here indicates that edible rice bran oil produced by low-technology conventional alkali refining is marginally competitive in world oil markets. There may be a limited market for export of rice bran oil to Japan where edible rice bran oil is well established and, because people believe it has special health attributes, sells at a premium. In fact, Japan does import some crude rice bran oil from other Asian countries. LDC's

where rice bran oil may be financially feasible are those where the domestic oilseed industry is subsidized to encourage production and processing and thus improved oil self sufficiency. India is the striking example in this area and rice bran oil extraction has expanded several fold over the last 15 years and the processing of the crude oil is becoming more sophisticated and upgraded from soap to food uses. Extrusion stabilization began in 1986 in India on an experimental basis and perhaps might still be considered in this category.

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